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JULY 2021

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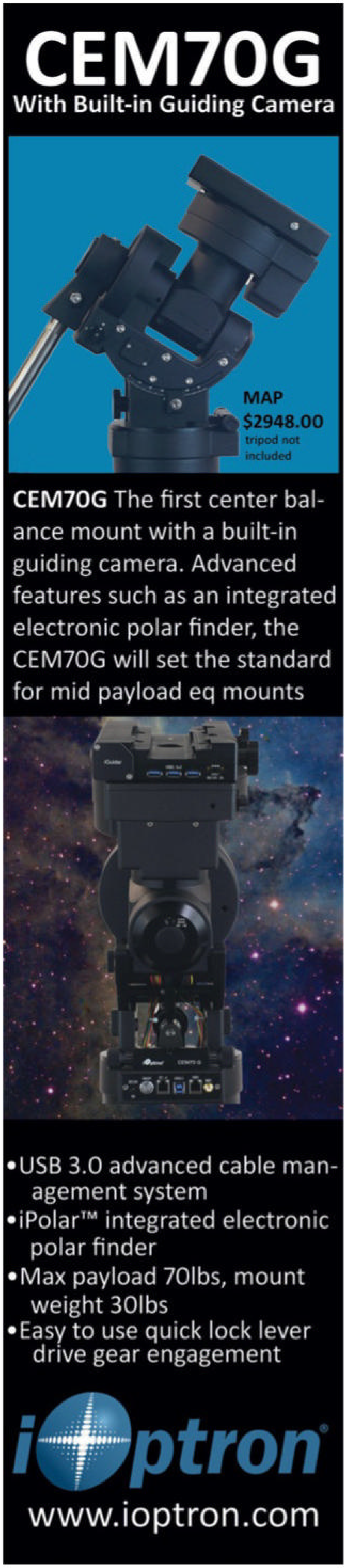
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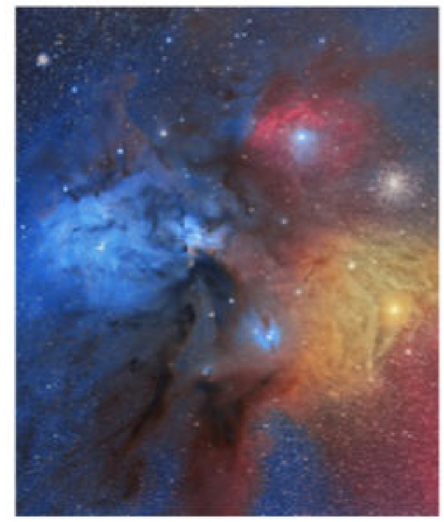

ON THE COVER

Small telescopes show myriad deep-sky objects, including globular cluster M4 in Scorpius and its region. TONY HALLAS

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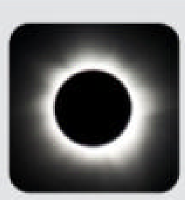
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Easy deep-sky observing

When I first started observing the sky, I was astonished that you could simply walk outside, set up a small telescope, and look far away into the heavens. Astronomy is one of the few sciences in which amateurs — pure lovers of the sky — can share the same laboratory, the universe itself, with the professionals.

Over the past couple of decades, with the availability of larger and larger backyard scopes and an information revolution, advanced deep-sky observers have relished going after increasingly exotic targets: galaxy clusters, quasars, carbon stars, and what have you. But we shouldn't forget that most sky observers have modest telescopes and many are getting their first views of distant objects beyond the solar system.

Astro enthusiast David Fuller's story on page 40 highlights some of the brightest and most spectacular gems of the sky you can see in binoculars and small telescopes. A 3-inch or 4-inch scope will reveal all these objects — a 6-inch or 8-inch glass will provide splendid views of them.

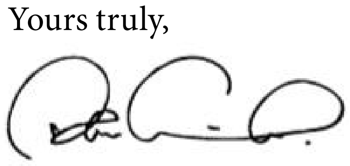
If you choose to, you can survey the entire life cycle of stars with a small telescope. It might begin with some views of emission nebulae, perhaps the Orion Nebula or the Lagoon Nebula, vast clouds of hydrogen gas slowly coalescing into infant stars. As the star clusters within them wink on, powerful stellar winds and radiation drive some of the gas away, sculpting impressive, even artistic shapes.

Young star clusters like the one that contained our Sun in its youth also present spectacles, such as the Pleiades or the Owl Cluster. Look closely and you'll see differing star colors (temperatures) among the myriad suns within. Patterns of stars seem to exist statically in our views of the cosmos, but will eventually be torn asunder as they orbit the galaxy.

You can also see the endpoints of a star's life, such as with a planetary nebula like the Ring, or the Dumbbell. In the late stages of a star like the Sun, these gas clouds give up their glows back into the interstellar medium, where they will be recycled once again.

Take your small scope outside on some nights this summer and you'll be amazed at what you can see from a simple planet in a simple galaxy in a great big universe.

Yours truly,



David J. Eicher
Editor

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The Antikythera Mechanism. GIOVANNI DALL'ORTO/WIKIMEDIA COMMONS

A special device

I want to say how much I enjoyed Raymond Shubinski's article on the Antikythera Mechanism (March 2021); it is a truly remarkable device. My interest stems from the fact I gave a PowerPoint presentation on the mechanism to the members of my club — Ford Amateur Astronomy Club — last May. Since giving my talk, I keep checking in online with the Antikythera Mechanism Research Project for more news. **—Don Klaser,** Center Line, MI

To the end of the universe

I must compliment you on the January 2021 special issue about the beginning, the middle, and the end of the universe. Having the entire history explained over several well-chosen topics, each of which have a succinct two- to three-page explanation, was a delight to read. Each story had the right amount of technical content and was just long enough to understand the concepts. **—Michael Schneider,** Liberty Hill, TX

Exploring Auriga

Congratulations on your article, "Spend some time in Auriga," in the February 2021 issue. It makes for a very interesting read and the format is just perfect: a concise narrative, a good star chart, and nice pictures of the various curiosities to be found in this constellation. I look forward to future similar reviews of other constellations. **—Jean-Louis Bellencourt,** Bégadan, Gironde, France

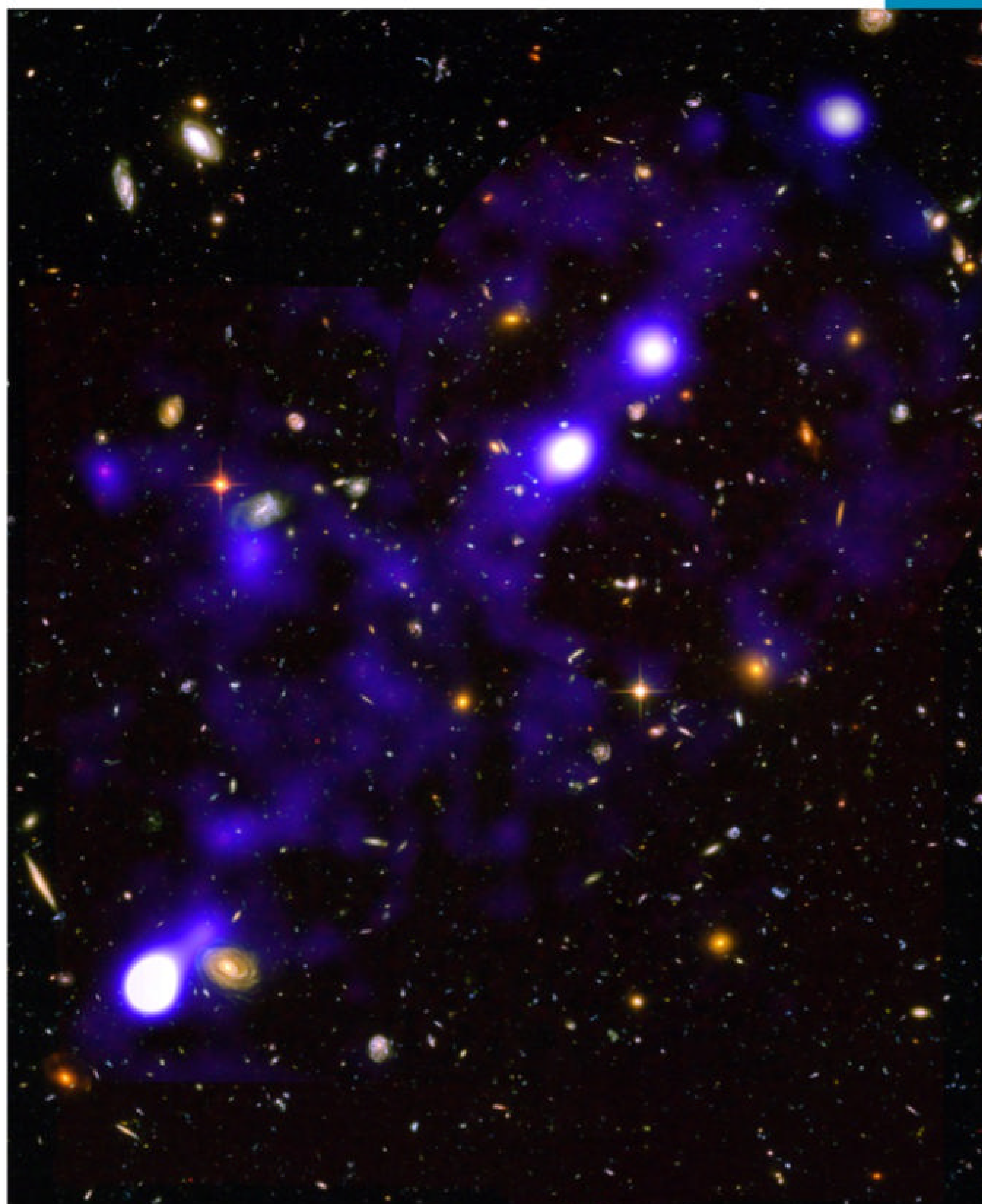
Correction

A caption on page 26 of the December 2020 issue stated Mars Odyssey's THEMIS imaging system had a visual resolution of 328 feet (100 meters) per pixel, while Mars Global Surveyor's TES instrument had a resolution of 59 feet (18 m) per pixel. These numbers should be transposed, with THEMIS capable of the better resolutions.

SNAPSHOT

STRANDS OF THE COSMIC WEB REVEALED

Astronomers capture filaments of gas crisscrossing the universe.



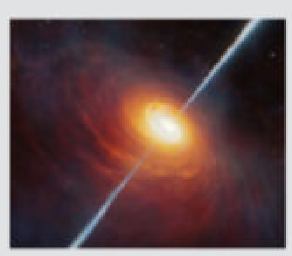
A giant web of invisible gas weaves throughout the universe, providing the scaffolding out of which galaxies are constructed. For decades, computer simulations have predicted the structure of this cosmic web. But until now, the only way to see it was indirectly, in a few select regions backlit by quasars — galaxies with bright, blazing cores.

In March, sophisticated instruments captured light emitted directly by the cool hydrogen gas filaments of the cosmic web. For 140 hours, astronomers focused the European Southern Observatory's Very Large Telescope (VLT) on a section of the Hubble Ultra Deep Field — the deepest view of the universe ever taken, which forms the background of this composite image. Using the VLT's Multi Unit Spectroscopic Explorer, or MUSE, the team was able to image cosmic filaments from around 1 billion years after the Big Bang. The filament pictured here (in purple-blue) extends more than 15 million light-years, or some 150 Milky Ways placed side by side.

The observations revealed a further surprise: billions of dwarf galaxies never before seen in the early universe, all birthing new stars. Accounting for these numerous small galaxies will be an important test for astronomers' models of how galaxies form and grow over time. — CAITLYN BUONGIORNO

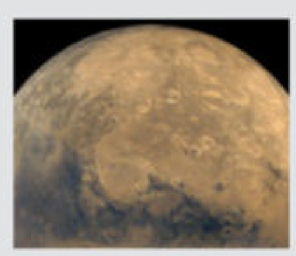
ROLAND BACON, DAVID MARY, ESO AND NASA. BOTTOM FROM LEFT: ESO/M. KORNMESSER; NASA/JPL-CALTECH/USGS; NASA/ROBERT MARKOWITZ

» HOT BYTES



TURN IT DOWN

Seen as it existed just 780 million years after the Big Bang, the quasar P172+18 is the oldest example yet found of a radio-loud quasar — a galaxy with an actively feeding supermassive black hole with jets emitting intense radio waves.



GONE TO GROUND

New research suggests that up to 99 percent of the water in the oceans that once covered Mars may be locked in minerals buried within the planet's crust. This challenges previous assumptions that most of Mars' water evaporated and escaped into space.

ONE STEP CLOSER

The core stage of NASA's Space Launch System rocket performed a test firing lasting eight minutes and 19 seconds, a key development milestone. The test simulated the rocket's planned launches of Moon-bound Artemis missions later this decade.

EVENT HORIZON TELESCOPE MAPS A BLACK HOLE'S MAGNETIC FIELD

New images of M87's supermassive black hole hint at how it fires its massive galaxy-spanning jets.

A NEW VIEW. The magnetic field around M87's supermassive black hole tweaks the orientation — or polarization — of light waves emitted from its accretion disk (yellow-orange). The polarization data, which is superimposed as lines on the disk in this image, reveals information about the magnetic field surrounding the object. EHT COLLABORATION

» Deep inside the elliptical galaxy M87 lurks a supermassive black hole with 6.5 billion times the mass of our Sun. In April 2019, this black hole became the first to have its shadow directly imaged, thanks to the Event Horizon Telescope (EHT) collaboration.

On March 24, 2021, the same collaboration released updated views of M87 that reveal a complex magnetic field around the black hole; astronomers believe the field could power the black hole's 5,000-light-year-long jet. The images accompany two papers published the same day in *The Astrophysical Journal Letters*, while a third related study has also been accepted for publication in *The Astrophysical Journal Letters.*

GETTING ORIENTED

When light passes near a strong magnetic field, its tug leaves an unmistakable mark. Like iron filings that align themselves and reveal the invisible magnetic field lines of a bar magnet, light waves "line up" — or become polarized — in the presence of magnetic fields. This can reveal clues about the field's structure and strength. And that's what the EHT collaboration has seen.

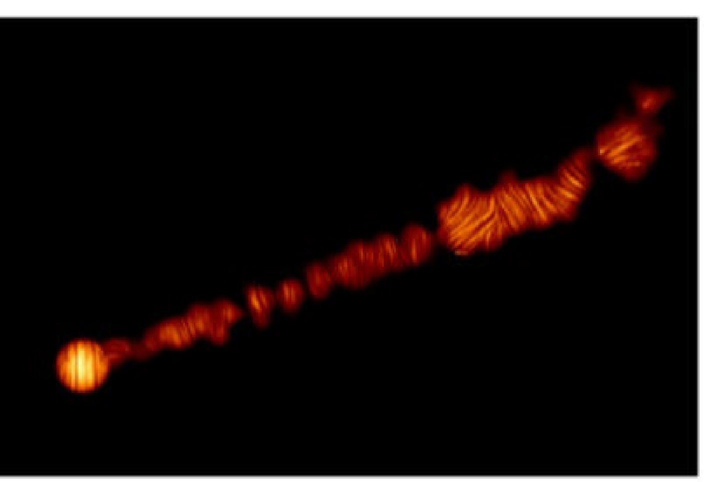
One new image shows the polarization of light coming from the accretion disk of hot material surrounding and flowing into M87's black hole. At

ESA/HUBBLE & NASA, M. GUERRERO; ACKNOWLEDGMENT: JUDY SCHMIDT

A born-again star

Revivals don't just happen in tents. They can also happen in deep space — like at the heart of Abell 78, an unusual planetary nebula imaged here by the Hubble Space Telescope and the Pan-STARRS telescope in Hawaii. Located about 5,000 light-years away in the constellation Cygnus, this sight was produced by a star that, in its death throes, blew its outer layers of gas into space. Most stars of similar mass settle into their graves quietly, producing no further nuclear reactions. But Abell 78 accumulated enough material in its outer layers to reignite nuclear fusion, triggering a second outburst that plowed into the initial halo, shocking it and creating the nebula's bright, complex inner structure. Abell 78 is one of only a handful of known so-called "born-again planetary nebulae." — MARK ZASTROW

least part of this ring is significantly polarized, which tells astronomers the disk contains highly magnetized gas. The team estimates the black hole's magnetic field strength is between 1 and 30 Gauss, or roughly two to 50 times stronger than Earth's magnetic field. And just outside the black hole's event horizon, or point of no return, researchers found the magnetic field is so strong it pushes some material away — even as most flows inward, forever disappearing inside the black hole.



ON THE MOVE. Data from the Atacama Large Millimeter/submillimeter Array — one of many radio telescopes that make up EHT — show the polarization of light in a section of the jet issuing from M87's black hole. The lines indicate the orientation of light waves in the jet, which evolves as material travels away from the object (located at left). ALMA (ESO/NAOJ/NRAO), GODDI ET AL.

JET SETTING

This ability of the magnetic field to serve as a gatekeeper, preventing at least some material from falling in, could explain how M87's black hole spews jets of material stretching thousands of light-years beyond the galaxy. Astronomers have long believed that magnetic fields play a crucial role in launching jets, but they are just now getting a detailed look at how exactly that process might occur. Such close-up views will help researchers better tweak their models of how matter and magnetic fields behave extremely close to black holes.

Although no EHT observations were made in 2019 or 2020, the collaboration plans to resume observing this year, with even more facilities linked into its network, which creates a virtual, planet-spanning dish. The world is eagerly waiting to see what it will show us next. — ALISON KLESMAN

QUICK TAKES

APOPHIS WILL PASS

Astronomers have used radar to more precisely map the orbit of the near-Earth asteroid Apophis, once deemed at risk of colliding with Earth. The new observations reveal it will not impact our planet for at least 100 years.

TWO-FACED

The rocky world LHS 3844b may be covered in erupting volcanoes — but only on one side. The dayside of this tidally locked planet is roughly 1,800 degrees Fahrenheit (1,000 degrees Celsius) hotter than its nightside. Simulations suggest this difference could cause magma to billow to the surface in one hemisphere, but not the other.

LUNAR PACT

China and Russia have signed a memorandum of understanding to jointly build a lunar space station. Whether on the surface or in lunar orbit, the station will allow researchers to test the technologies necessary for long-term human and robotic exploration of the Moon.

NEW VEGA

Astronomers have found evidence that the nearby star Vega hosts a giant planet so close that a single orbit (or year) takes just 2.5 Earth days. If confirmed, the world might also rank as the second hottest known, with a surface temperature averaging some 5,400 F (3,000 C).

SIDESTEPPING SATELLITES

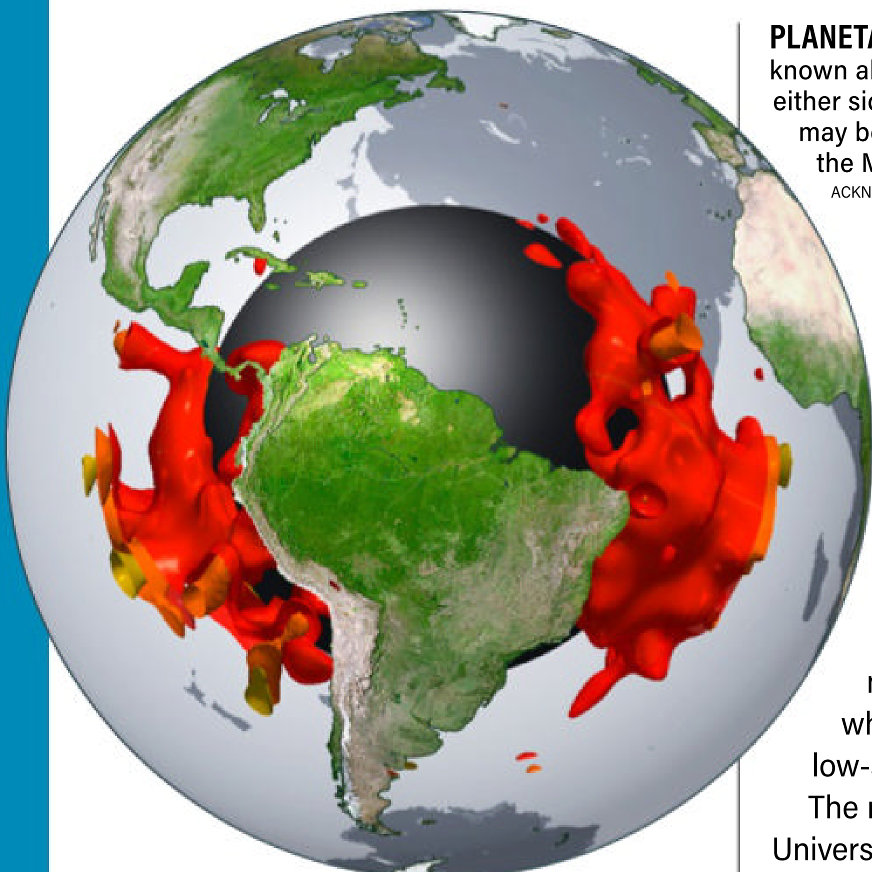
SpaceX and NASA have formally agreed to coordinate and share information with each other to avoid collisions between SpaceX's satellites and NASA spacecraft. The agreement specifies SpaceX will cede the right of way to NASA craft.

TUG ON A BUG

Physicists have measured the smallest gravitational force yet. The team recorded how a pendulum twisted about as they moved a tiny gold sphere about the mass of a ladybug to and fro, minutely changing the local gravitational field.

— JAKE PARKS

Moon-forming impactor remains hidden within Earth



PLANETARY GRAVEYARD. Seismologists have long known about the mysterious large piles of rock on either side of Earth's mantle. Some suspect they may be connected to the impactor that created the Moon, known as Theia. *ASTRONOMY*: ROEN KELLY; ACKNOWLEDGEMENT: EDWARD GARNERO, QIAN YUAN, ASU

The Moon is a familiar presence in our sky, but that wasn't always the case. Most scientists believe our natural satellite formed after a Mars-sized protoplanet, called Theia, careened into Earth about 4.5 billion years ago. The impact blasted a spray of rocky debris from both Theia and Earth into orbit around our planet; the debris eventually coalesced into the Moon.

Models of this Giant Impact Hypothesis suggest that Theia's core quickly settled and merged with our planet's own core. But there is still a large chunk of the impactor's mass unaccounted for. A recent study, presented at the 52nd Lunar and Planetary Science Conference in early March, may bring scientists one step nearer to finding the rest of Theia.

According to the study, an impact with a Theia closer in size to Earth — and about 1.5 to 3.5 percent more dense — would have created sizable piles of Theia material deep within our planet's mantle. And, as it turns out, geologists already know Earth has two blobs of rock sitting near its core that fit the bill.

These continent-sized layers of rock have long puzzled researchers. Located below Africa and the Pacific Ocean, they appear to sit at the bottom of the mantle, extending upward as far as 621 miles (1,000 kilometers) above the core-mantle boundary. These areas abruptly slow down seismic waves from earthquakes as they travel through the planet, suggesting they are chemically different and denser than the mantle rock around them — that's why researchers call these blobs large low-shear velocity provinces (LLSVPs).

The new study, led by Arizona State University graduate student Qian Yuan, isn't the first time the LLSVPs have been brought up in conjunction with the Giant Impact Hypothesis. But it is the first time anyone has put together a serious case with multiple kinds of evidence for the connection.

Still, scientists need more evidence to solidify a link between the LLSVPs and Theia. For starters, they aren't sure the LLSVPs are as solid as assumed. Instead, they may be more like a bundle of tubes rather than piles of dense rock. Luckily, Iceland and Samoa have lava flows that reach all the way down to the LLSVPs, making it possible for researchers to collect samples from them. In the future, scientists might make a geochemical comparison between the LLSVPs samples and rocks from the Moon's mantle. NASA and China are both planning future missions to the Moon that may collect such rocks.

If the LLSVPs really are Theia's remains, they may not be alone. More and more pockets of material in the deep mantle have been spotted recently, which could be evidence of the sunken remains of other miniature planets colliding with a young Earth. The LLSVPs may be just the tip of the cannibalized-planet iceberg. – C.B.

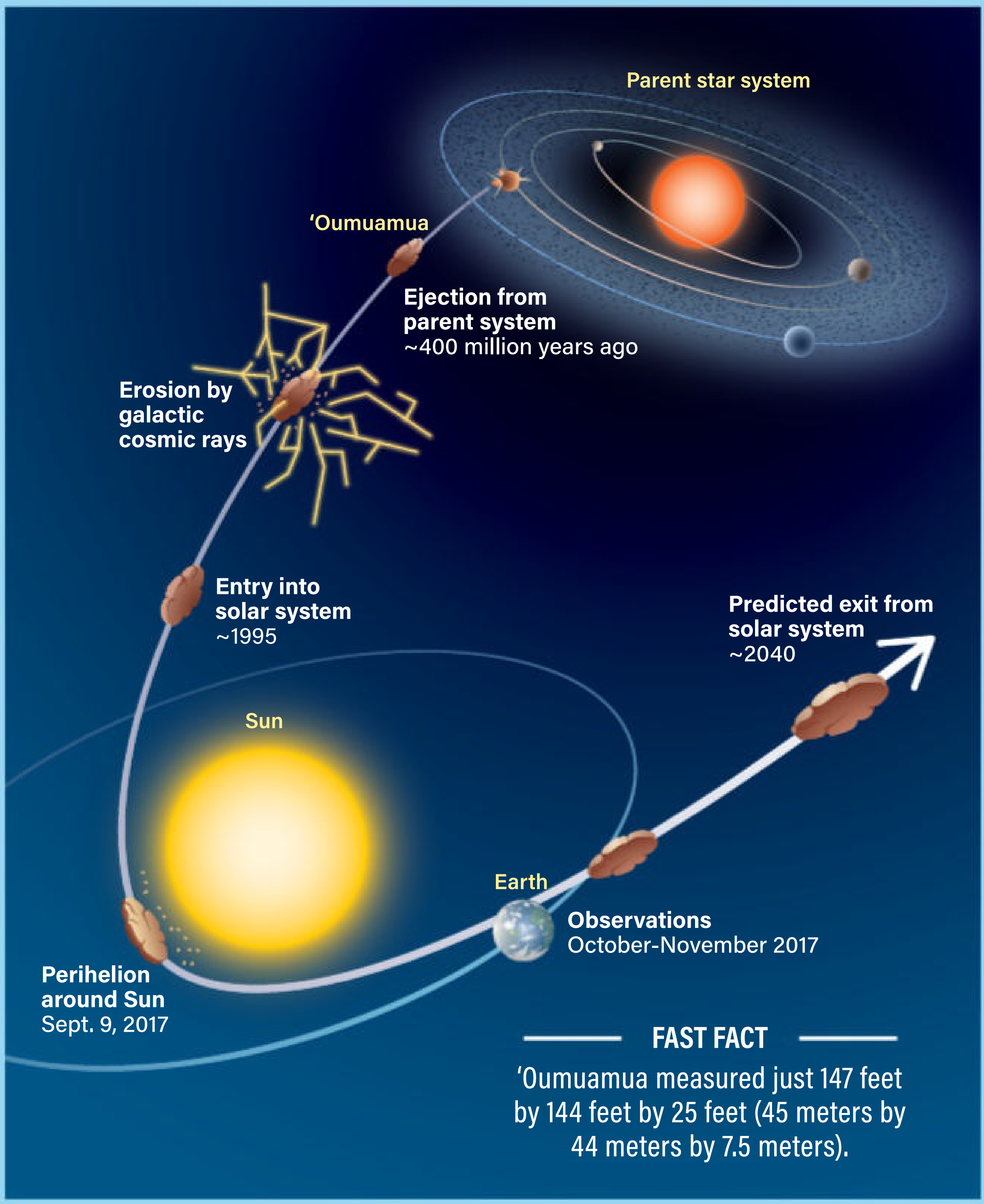
NASA, ESA, AND R. HUMPHREYS (UNIVERSITY OF MINNESOTA)

ANOTHER STAR SNEEZES LIKE BETELGEUSE

The red hypergiant star VY Canis Majoris, 4,000 light-years distant, is in a turbulent phase near the end of its life. Wracked by pulsations, it is expelling mass in a series of dusty knots and arcs. The resolution in this recent Hubble image is high enough that researchers could estimate when several of these outbursts occurred, ranging from more than 1,000 years ago to as recently as about 1990. By comparing these timeframes to historical records of VY Canis Majoris' brightness, the team found that many outbursts corresponded to periods when the star's brightness temporarily faded. The findings, published in *The Astronomical Journal* Feb. 4, suggest VY Canis Majoris has a history of events similar to the recent dimming of another giant star: Betelgeuse. In 2019 and 2020, that star mysteriously temporarily faded in brightness. Hubble imaging suggested that it, too, had ejected a cloud of dust that blotted out some of its light. – M.Z.

‘OUMUAMUA’S TRIP AROUND THE SUN

UNEXPLAINED VISITOR. In October 2017, the first interstellar interloper was discovered by the Pan-STARRS observatory in Hawaii. Named 1I/2017 U1 ‘Oumuamua — meaning *scout* or *messenger* in Hawaiian — the object defied classification. For starters, ‘Oumuamua’s velocity upon entering the solar system indicated it had only been traveling through interstellar space for a little over a billion years or so. And unlike any other object in our solar system, ‘Oumuamua was flattened, like a pancake. Although most researchers categorized the strange object as a comet, it didn’t behave like any they’d observed before. Usually, as comets approach the Sun and warm up, they release particles and dust that reflect sunlight and appear like a tail when sunlight reflects off them. But ‘Oumuamua never developed such a tail, indicating the object was made of ices different from the comets researchers are accustomed to seeing. In fact, an object made of solid nitrogen would provide an exact match to these odd features, according to a new study published March 16 in the *Journal of Geophysical Research: Planets*. There’s one object in our solar system with a surface of solid nitrogen: Pluto. So, it’s possible that about half a billion years ago, a collision in a distant planetary system knocked ‘Oumuamua off the surface of a similarly nitrogen-rich object and propelled it from its home system to ours. – C.B.



FAST FACT

‘Oumuamua measured just 147 feet by 144 feet by 25 feet (45 meters by 44 meters by 7.5 meters).

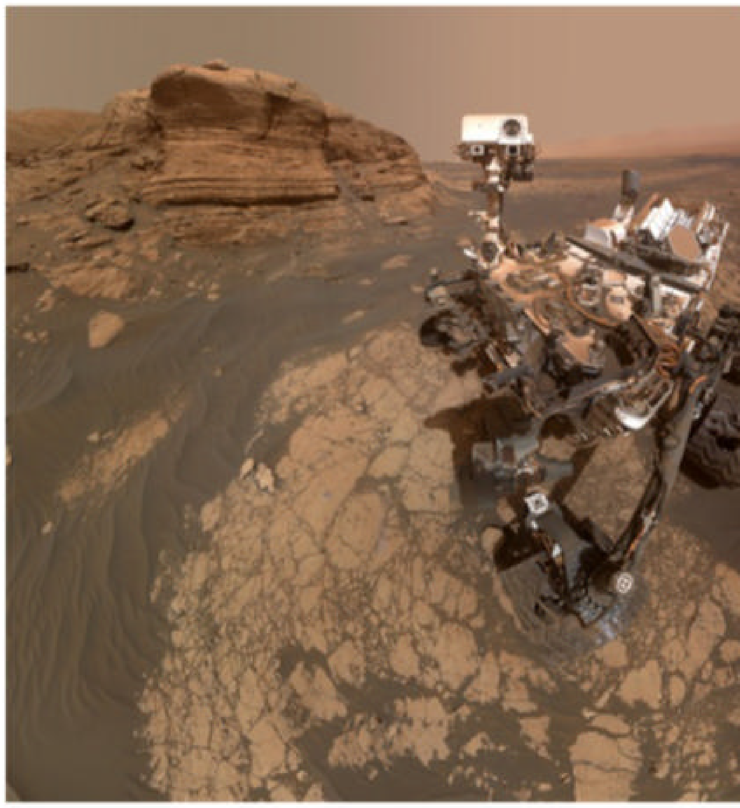
ASTRONOMY: ROEN KELLY

$30 million

The lower end of the estimated cost to clean up the debris from Arecibo’s disastrous collapse, according to a National Science Foundation report.

Camera ready

Capturing the perfect picture is never easy. Luckily, Curiosity has both the perfect camera and selfie stick: its Mars Hand Lens Imager, attached to the end of its robotic arm. This photo comprises 60 images taken with that camera, as well as another 11 taken with the rover’s Mastcam, which sits atop its head. Curiosity is posing in front of a rock formation that mission scientists named after the French mountain Mont Mercou. The rover also took the opportunity to drill into a nearby rock, retrieving its 30th sample. Curiosity came across this feature as it was trekking up Mount Sharp, moving out of a clay-rich area to a region with sulfate-rich soil. Scientists are hoping this transition region will reveal clues to how Mars became the desert planet it is today. – HAILEY ROSE MCLAUGHLIN



NASA/JPL-CALTECH/MSSS

Mars may generate the zodiacal light

CAUGHT RED-SANDED. Astronomers have long believed the dust that creates the zodiacal light is shed by comets and asteroids. But a chance find by Juno implicates a different source: Mars. ESO/Y. BELETSKY

» The zodiacal light is a cone-shaped glow in the night sky produced by sunlight reflecting off tiny dust grains in the inner solar system. Astronomers have long believed this dust was shed by asteroids and comets. But a study published March 9 in *JGR Planets* points to a different possible source: Mars.

As the NASA Juno spacecraft journeyed from Earth to Jupiter between 2011 and 2016, one of its four star-tracking cameras searched for undiscovered asteroids. Thousands of photos poured in. They showed not asteroids, but bits of debris, just 0.04 inch (1 millimeter) across or smaller. Eventually, mission scientists realized these particles were coming from the spacecraft itself: Interplanetary dust particles were slamming into the backs of Juno's three 30-foot-long (9 meters) solar panels at some 10,000 mph (16,000 km/h). Fortunately, this portion of the panels was strong enough to withstand the bombardment. Thus, the spacecraft became a giant dust detector, with a collecting area thousands of times larger than previous dedicated dust-mapping experiments.

Juno showed that the zodiacal dust cloud stretches from Earth's orbit to just beyond the orbit of Mars. Earth's gravitational influence defines the inner edge of the cloud, while Jupiter's gravity sculpts its outer edge. Within the cloud, researchers found that the most impacts — and thus the majority of the dust — occurred in a region with orbital properties closely resembling those of Mars. Because so much of the cloud's dust shares Mars' circular orbit around the Sun and its inclination to the ecliptic plane of the solar system, the researchers say this points to the Red Planet as its origin.

So, the team modeled how dust with Mars' orbital properties would interact with Jupiter's gravity over time and how sunlight would reflect off such dust. The results closely match the actual zodiacal light. "That is, in my view, a confirmation that we know exactly how these particles are orbiting in our solar system and where they originate," Jack Connerney, Juno's deputy principal investigator and lead investigator on the spacecraft's magnetometer, said in a press release.

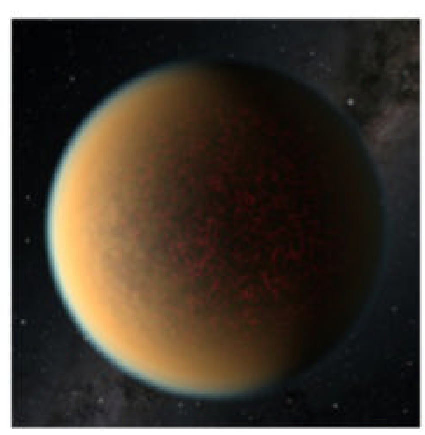
Despite the find, researchers aren't yet sure exactly how dust from Mars escapes its gravity to spread out between the planets. But knowing how the dust is distributed will now help mission planners better safeguard future spacecraft against similar interplanetary dust collisions. —A.K.

Volcanoes may have replenished a super-Earth's atmosphere

Once upon a time, GJ 1132 b was a gas giant planet 40 light-years from Earth in the constellation Vela. Then, theory suggests, radiation from its parent star burned off its envelope of hydrogen and helium gas, leaving behind only a rocky core — an airless super-Earth 1.6 times the mass of our planet.

But recently, a group led by researchers at NASA's Jet Propulsion Laboratory (JPL) analyzed Hubble Space Telescope observations from 2016 and found that the planet seems to have reestablished an atmosphere. Furthermore, spectral analysis shows that the composition of the gases — hydrogen-rich and low in oxygen — suggest a volcanic origin.

Before GJ 1132 b, all known exoplanet atmospheres were thought to have come from gas left over from the planet's initial formation. But based on our own solar system's history, we know that rocky planets can undergo full



VOLCANIC MAKEOVER. For the first time, astronomers have discovered an exoplanet with an atmosphere formed by volcanic activity. NASA, ESA, AND R. HURT (IPAC/CALTECH)

atmospheric makeovers later in life; Earth's atmosphere has been completely remade twice, first by volcanic activity and meteorite impacts, and then by the emergence of life.

The new work — posted March 10 to the *arXiv* preprint server and accepted for publication in *The Astronomical Journal* — is the first time a secondary atmosphere has been reported on an exoplanet.

To explain its origins, the authors reference a 2019 study that suggests a nascent planet could absorb some of its initial hydrogen atmosphere into its molten mantle. This reservoir of hydrogen, the team proposes, could be released later through volcanic activity. —ARWEN RIMMER

The third dimension

What does it take to see in 3D?

The author stands at the eyepieces of his binoviewer, located in his new home observatory. Binoviewers deliver legitimate 3D views of distant celestial scenes. BOB BERMAN

Sales of binoviewers for telescopes and matching eyepieces have exploded in the past five years, showing that backyard astronomers are really getting into two-eye observing. Binoviewers split light from your telescope into two beams, sending one to each eye for more comfortable — and natural — viewing that often turns celestial scenes three-dimensional. Nonetheless, you may have heard that binoviewers do not deliver true 3D. So, let's examine this realm in all its dimensionality.

As readers probably know, seeing in three dimensions requires that each eye see a slightly different image. In practice, distant objects appear identical in both eyes, while foreground targets appear shifted relative to those far-off markers. The brain uses these disparate images to stitch together the 3D world we see in front of us — or, at least, *seem* to see in front of us.

Backyard astronomers are really getting into two-eye observing.

As Roy Bishop, former editor of *The Royal Astronomical Society of Canada's Observer's Handbook*, repeated in each annual edition, visual images occur strictly within the skull. Language, custom, and a sort of neurological magic make us regard the visual world as occurring outside our bodies. In reality, photons of light possess neither color nor brightness. The world that appears to unfold in front of our noses is solely our mind's concoction, the result of billions of neurons creating the visual experience.

This is an important distinction because it's easy to provoke the perception of 3D without one object actually being situated in front of another. Perhaps — like me — you have at some point slightly crossed your eyes while in front of a chain-link fence and watched it then acquire a "pop-out" appearance as your brain creates an incorrect sense of 3D. Our editor, David Eicher, forces our minds to do something similar in his 3D astronomy books. An actual 3D view of even the nearest nebula would require our eyes to be situated at least 8 light-years apart. To create a sense of depth on a printed page or screen, pictures of celestial objects are painstakingly (and minutely) altered so that each eye views image fragments displaced a bit. Our brains do the rest.

But what about real-life 3D? In the 19th century, Hermann Von Helmholtz determined that for humans, the maximum distance at which objects appear with stereopsis — one object seeming closer than the other — is 650 feet (200 meters), or about 2½ city blocks. However, some researchers believe our 3D experience may actually stretch to 0.6 mile (1 kilometer). Binoculars extend this perception to greater distances because their objective lenses are mounted farther apart than human eyes. The depth effect is dramatic, which is one of the reasons binoculars are so much fun to use.

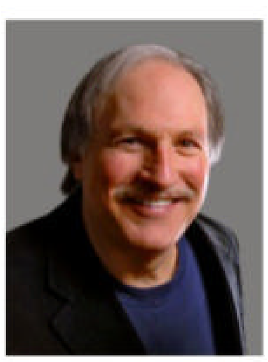
Which brings us back to the current binoviewer craze. I'm one of those who is totally hooked. When I decadently built a second observatory near my home, it not only provided a telescope two minutes from my pillow, it also included a 5-inch refractor perfect for a binoviewer. So, I discontinued decades of deep-space viewing with my 40-year-old, 12.5-inch, pier-mounted reflector and turned exclusively to the Moon and planets, always with the binoviewer using 60x to 200x magnification.

It blew me away. But since binoviewers deliver identical images to each eye, it's not actual 3D, right?

Well, it looks like 3D. It feels like 3D. And, with the slow-wittedness my friends assure me I've not outgrown, I've realized that it is indeed 3D. That's because distant objects have zero parallax to begin with. So, when both eyes see identical images, the brain perceives the scene as being very distant. Since astronomical scenes are indeed far away, a binoviewer delivers the identical celestial view you'd get if each eye received an image from a separate telescope, even if the scopes were a mile apart. It's a legitimate 3D perception.

The only thing that spoils it is poor seeing: The 3D effect is diminished when both eyes discern identical simultaneous distortions. So, the next time you're at the eyepiece and think, "Wow, another night of wiggly seeing! Must be a day ending in y!" do yourself a favor — and I don't mean move to Mauna Kea. Merely delay the session and return to your regular life, which at least reliably unfolds in full stereopsis.

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman**



BY BOB BERMAN
Bob's newest book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

Apollo 15

NASA hits its stride

This view from the slopes of Mount Hadley Delta, near St. George Crater, takes in the Hadley Rille. On the left is a boulder that Scott and Irwin sampled. ALL IMAGES BY NASA AND FILM SCANS/LAB PHOTOS BY THE JOHNSON SPACE CENTER UNLESS OTHERWISE NOTED

Scott: Oh, look back there, Jim! Look at that. Oh, look at that! Isn't that something? We're up on a slope, Joe, and we're looking back down into the valley and —

Irwin: That's beautiful.

Scott: That is spectacular!

Armed with the first rover, intrepid astronauts drove lunar science forward. BY MARK ZASTROW

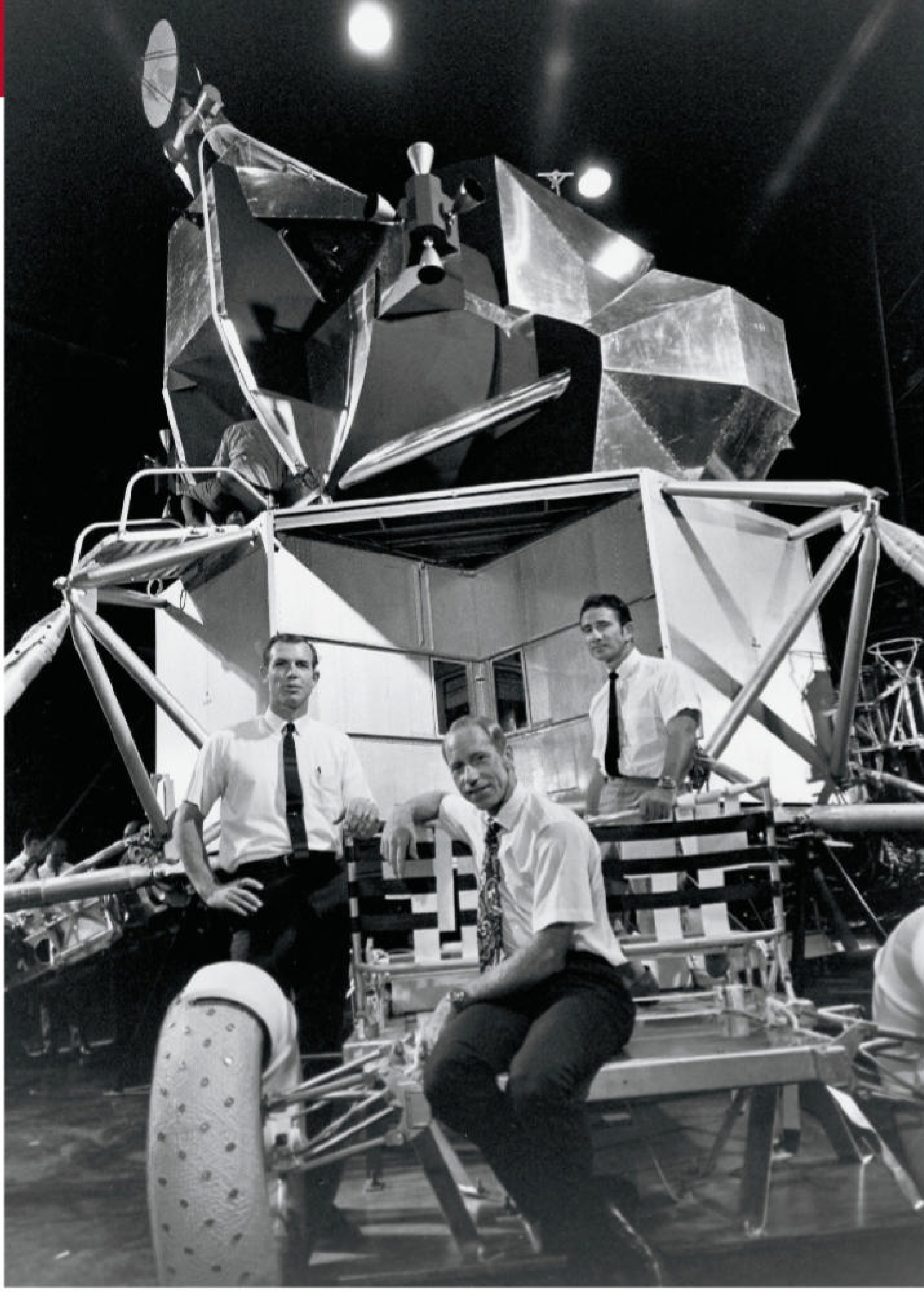
AFTER THREE SUCCESSFUL LUNAR LANDINGS — and the "successful failure" of Apollo 13 — NASA was ready to swing for the scientific fences. The previous landings had been considered test flights, H series missions in NASA parlance, intended to show that landing on the Moon could be done. Apollo 15 would be the first of the J series, with more ambitious scientific objectives.

To meet those goals, Apollo 15's crew brought all kinds of new and upgraded tools: a percussive drill to collect core samples and plant heat probes; brand-new 500mm telephoto lenses; and, most famously, the "Moon buggy" called the Lunar Roving Vehicle (LRV). Built by Boeing, the rover promised to dramatically expand the range of the astronauts' field expeditions.

Dave Scott and Jim Irwin train for their mission by exploring an artificial crater field created by geologists to mimic a lunar landscape near Crater Lake in Arizona.

After the precision landings of Apollo 12 and 14, NASA also got aggressive with its choice of landing site, the Hadley Plain. This roughly 6-mile-wide (10 kilometers) clearing was hemmed in by the Apennine Mountains and bordered by the 0.6-mile-wide (1 km) meandering canyon called Hadley Rille, which may have been created by volcanic activity. It was a spectacular setting with great geological potential.

Commander David Scott, a NASA veteran, was a perfect match for this mission. More than any other moonwalker to date, Scott embraced the role of field geologist and sought to learn as much as he could under the tutelage of Caltech geologist Leon Silver. His choice of name for the Command Module (CM) reflected his scientific enthusiasm: *Endeavour,* after the vessel that carried British explorer Captain James Cook on his first scientific voyage.



From left to right, Dave Scott, Al Worden, and Jim Irwin pose with a lunar rover simulator in Houston.

Scott was joined on the mission by Lunar Module Pilot James Irwin and Command Module Pilot Alfred Worden, two first-time astronauts who'd joined NASA's corps in 1966. The trio attacked their mission with gusto and a sense of awe that lives on in the transcripts and audio recordings — and here, in this story.

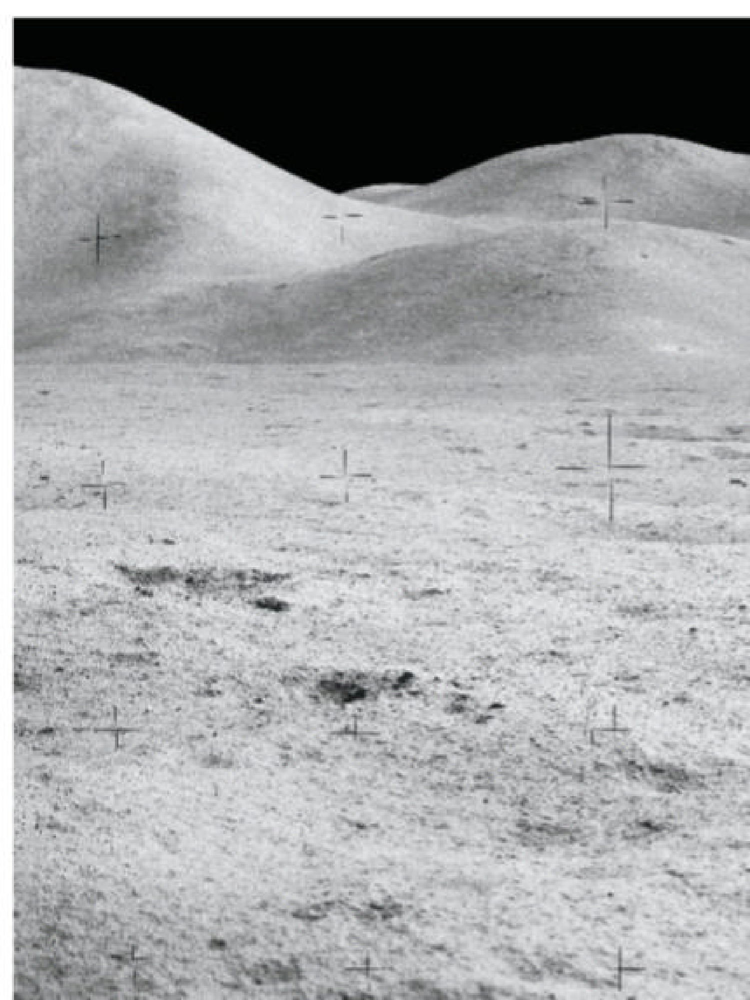
* * *

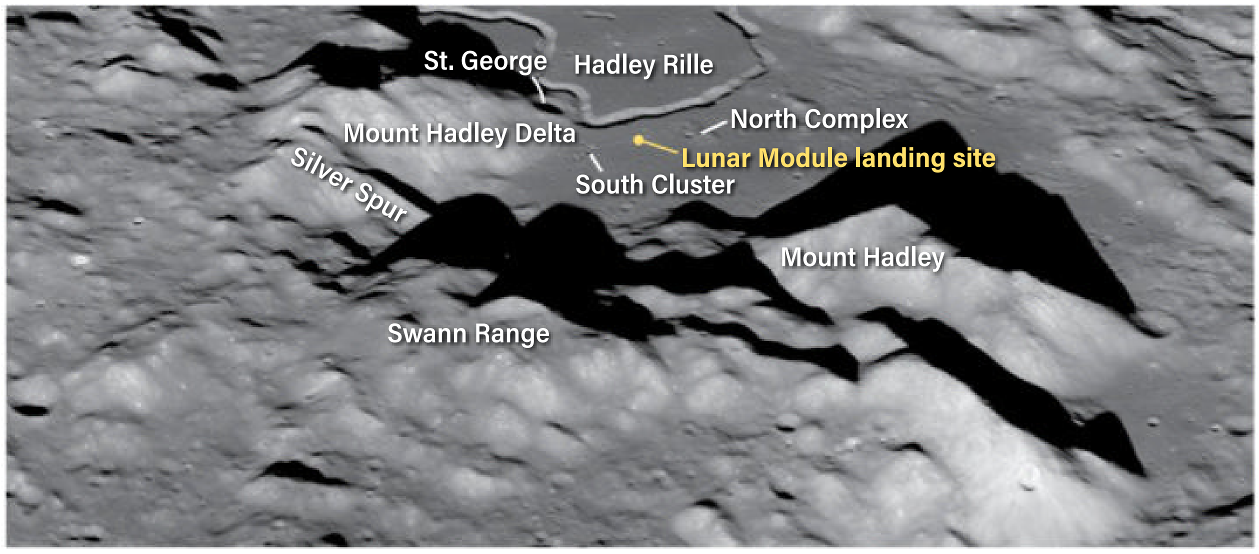
Apollo 15 lifted off exactly on schedule July 26, 1971, at 9:34 A.M. EDT, keeping to a tight mission timeline that would ensure a favorable Sun angle when Scott and Irwin arrived at the Apennine Mountains on their landing approach. As the Saturn V rocket climbed out over the Atlantic, Scott checked in with his rookie crewmates.

SCOTT: How we doing, Al?
WORDEN: We're doing fine; 63 miles [altitude].
SCOTT: Good.
IRWIN: Everything looks good over here.
SCOTT: OK.
WORDEN: Just — looks just about a hundred feet per second down on the H-dot [climb rate], but everything else looks fine.
SCOTT: OK, I got the big fireball going by at staging. I don't know whether you saw it or not. That beauty really goes.
WORDEN: Yes.
GORDON FULLERTON, CAPSULE COMMUNICATOR (CAPCOM): Fifteen, Houston. At four [minutes], the

Apollo 15 clears the tower at Launch Complex 39A at the Kennedy Space Center on July 26, 1971.
NASA/J.L. PICKERING

Scott leans in to take a photograph while on geology training in Hawaii.





To clear the Swann Range, the approach path of Apollo 15's LM was at an angle of 26° — much steeper than the 15° path flown by previous missions. NASA/GSFC/ASU/GONETOPLAID

guidance has converged. The CMC [Command Module Computer] is go and everything looks good.

SCOTT: OK, Gordo. Looks good up here.

IRWIN: Man, I got the Moon in my window.

SCOTT: Yes, sir. It's out there.

* * *

The three-day journey of Endeavour *and the Lunar Module (LM)* Falcon *to lunar orbit was a calm one, interrupted only by having to troubleshoot a short circuit in the firing switch for the Service Module (SM) thrusters. On the afternoon of July 29, the crew slipped into lunar orbit with a perfectly executed braking burn. As they began their first revolution, the crew tried to relay descriptions to Houston of the geological features they were seeing.*

SCOTT: And, you know, as we look at all this after the many months we've been studying the Moon and learning all the technical features and names and everything, why — when you get it all at once, it's just absolutely overwhelming. There are so many different things down there and such a great variety of landforms and stratigraphy and albedo, that's it's hard for the mental computer to sort it all out and give it back to you. I hope over the next few days, we can sort of get our minds organized and get a little more precise on what we're seeing. But I'll tell you, this is absolutely mind-boggling up here.

KARL GORDON HENIZE (CAPCOM): Gentlemen, I can well imagine that a foreign planet must be a weird thing to see.

As Apollo 15 continued in its orbit just 70 miles (113 km) or so above the lunar surface, the Apennine Mountains began to appear on the horizon — the very mountains Scott and Irwin would negotiate the next day.

SCOTT: And, Karl. We're approaching the Apennine Mountains, and that is indeed a spectacular view.

HENIZE: Roger.

WORDEN: Sure is, Karl. No question about those mountains being there and where we're at with them.

HENIZE: They stand up on your horizon, do they?

WORDEN: Yes, tremendous relief as we approach the mountain, Karl. […]

SCOTT: Houston, as we cross out of [Mare] Serenitatis into the Apennines, why, it's just — unreal. You know, those are very poor descriptive terms, but the — the mountains jut up […] here in great relief. I'm sure the guys who've been here before can probably sit down over a cup of coffee and tell you. But the relief is really pervasive.

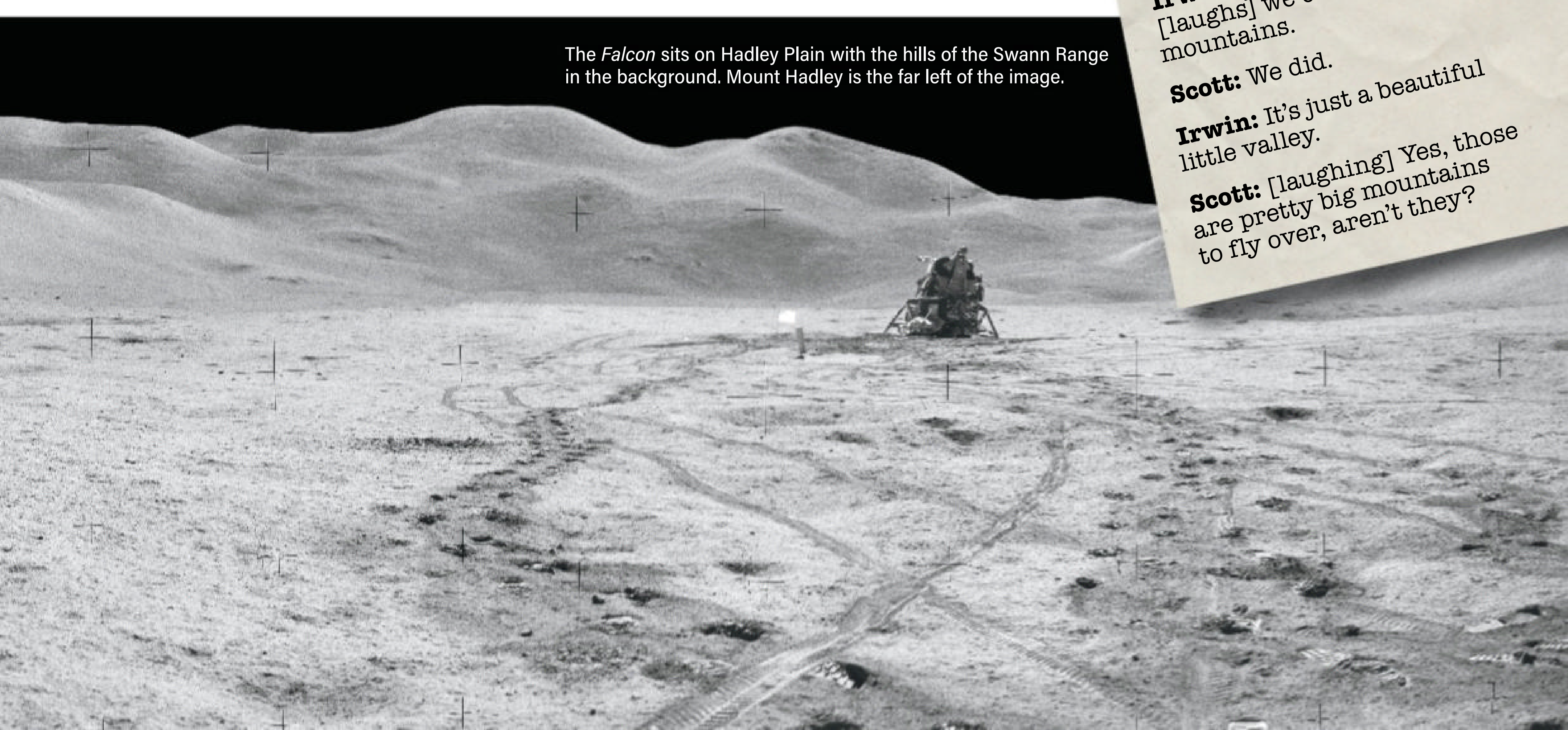
HENIZE: You're the first man to fly over this mountain range, Dave. I guess

Irwin: I can't believe, uh... [laughs] we came over those mountains.

Scott: We did.

Irwin: It's just a beautiful little valley.

Scott: [laughing] Yes, those are pretty big mountains to fly over, aren't they?



The *Falcon* sits on Hadley Plain with the hills of the Swann Range in the background. Mount Hadley is the far left of the image.

NASA/DAVID HARLAND/KIPP TEAGUE

Scott took this panorama of Mount Hadley Delta — roughly 2 miles (3.2 km) in the distance — from the top hatch of the LM shortly after landing. The prominent feature on the left flank is Silver Spur, named after geologist Leon Silver. In contrast to the lineations on Mount Hadley Delta, which are mostly thought to be lighting artifacts, the layering on Silver Spur is likely formed by genuine bedrock layers.

pretty soon you're going to be over the — over the landing site, aren't you?

SCOTT: Roger. But I'm afraid it'll be dark today.

HENIZE: That's right.

* * *

Scott and Irwin got their chance to see it the next day, when lunar dawn broke over the Hadley Plain. As they descended in Falcon, *they soared over the Sea of Serenity, heading for the mighty Apennines. Their landing site, the Hadley Plain, was tucked against the other side of the range. To get there, they descended at a much steeper angle than any previous Apollo mission, cleared a 12,000-foot-high ridgeline (3,650 meters), and shot the gap between Mount Hadley (13,000 feet [4,000 m]) and Mount Hadley Delta (11,500 feet [3,500 m]).*

EDGAR MITCHELL (CAPCOM): *Falcon*, Houston. We expect you may be a little south of the site, maybe 3,000 feet.

IRWIN: OK. Coming up on 8,000 [feet in altitude].

SCOTT: OK.

IRWIN: 7,000 feet.

Through most of the powered descent, the LM was flying on its side, braking with its engine facing forward. As they passed 7,000 feet (2,130 m), the LM rotated to an upright position, allowing the pair to see their surrounding landscape out the windows. Although they'd done extensive simulator training, that didn't prepare them for the awesome sight of Mount Hadley Delta towering nearly a mile (1.6 km) above them.

That view also helped Scott orient himself and immediately correct the computer's landing trajectory with a hard roll.

IRWIN: P64! *[Program 64 was the guidance computer's landing program.]*

SCOTT: OK.

IRWIN: We have LPD. *[The Landing Point Designator mode allowed Scott to alter the computer's landing target.]*

SCOTT: LPD. Coming right.

The rest of the descent was all business as Irwin called out LPD and altitude information to Scott.

IRWIN: You're 200 [feet], minus 11 [feet descent rate]. 150, minus 7. Minus 6. 120 feet, minus 6.

SCOTT: OK, I've got some dust.

The descent continued, until the LM fell the final few feet to the surface, landing with a hard jolt.

IRWIN: Contact! Bam!

SCOTT: OK Houston, the *Falcon* is on the Plain at Hadley.

MITCHELL: Roger, roger, *Falcon*. *[Applause in the background.]*

IRWIN: No denying that. We had contact!

A couple of hours later, the astronauts popped open the LM top hatch so that Scott could conduct a short visual survey of the site's stunning landscape. For 10 minutes, he gave a detailed description of what he saw to Mission Control, with the geologists in the back room — where non-flight controller support staff huddled — hanging on his every word. The next day, the pair emerged from the LM for their first proper extravehicular activity (EVA).

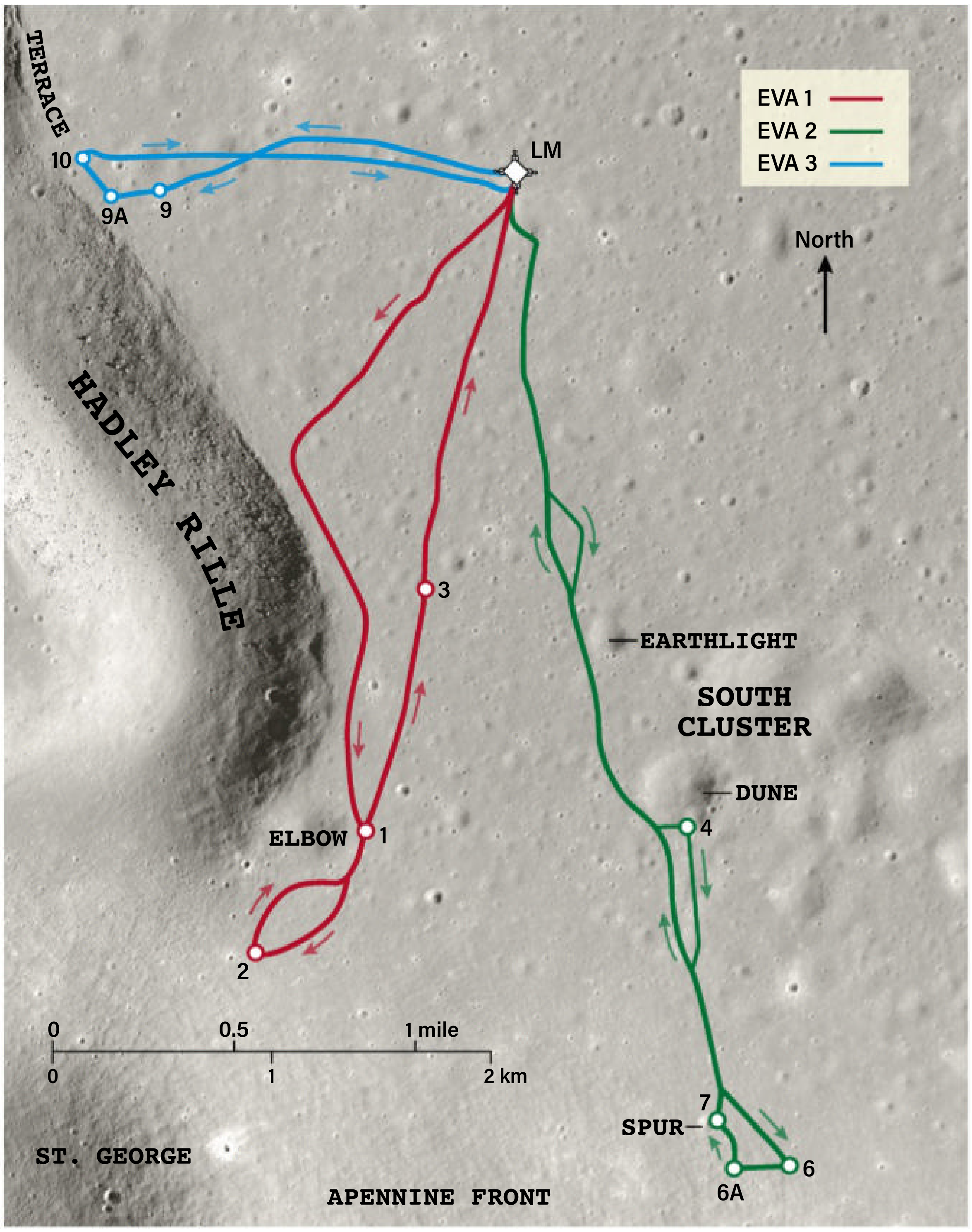
SCOTT: OK, Houston. As I stand out here in the wonders of the unknown at Hadley, I sort of realize there's a fundamental truth to our nature. Man must explore. And this is exploration at its greatest.

The first item on the agenda was to unload the rover, unfold it, fire it up, and give it a test drive.

LEFT: Scott and Irwin took several samples of soil and glass fragments from this 3-foot-wide (1 m) crater at Station 6 on the lower slopes of Mount Hadley Delta near Spur Crater. At some point after it was collected, the largest one fragmented. CENTER: Some of the fragments are pictured here in the lab at Johnson Space Center in Houston, where each Apollo sample was meticulously processed and documented. RIGHT: This image of a thin section of the sample is a microscope view in polarized light.

ROVING HADLEY PLAIN

The total traverse distance of 17.5 miles (28.2 km) that Scott and Irwin traveled in the lunar rover was more than eight times longer than the two EVAs of Apollo 14, which were carried out on foot. Apollo 15's crew could have covered even more ground, had problems with the percussive drill not forced them to shorten their third EVA.



ASTRONOMY: ROEN KELLY, AFTER ERIC JONES AND THOMAS SCHWAGMEIER. BASEMAP IMAGE: NASA/GSFC/ARIZONA STATE UNIVERSITY

SCOTT: OK, looks like the brake's on, reverse is down, so I'll see if I can't hop in it. *[Pause.]* That's a reasonable fit.

JOE ALLEN (CAPCOM): OK, Dave. And buckle up for safety here.

SCOTT: Oh, yes. OK, safety belts on. […] OK, got a detent; we're moving.

ALLEN: Extraordinary.

SCOTT: Hey, Jim, you can probably tell me if I've got any rear steering.

For greater maneuverability, the rover's front and rear axles were both capable of turning.

Scott: Incidentally, Joe, thinking back on something we saw yesterday down towards Mount Hadley, we saw three sort of suggestions of beddings or horizontal linear lines at the base of Mount Hadley. And I got to thinking last night, maybe that was the high-water mark [of lava] for the basin at one time, because there are only three of them down there, and they were unique at the base of that mountain.

Irwin: Boy, I can't get over those lineations, that layering at Mount Hadley.

Scott: Boy, I can't either. That's really spectacular.

Irwin: That's really beautiful. Talk about organization!

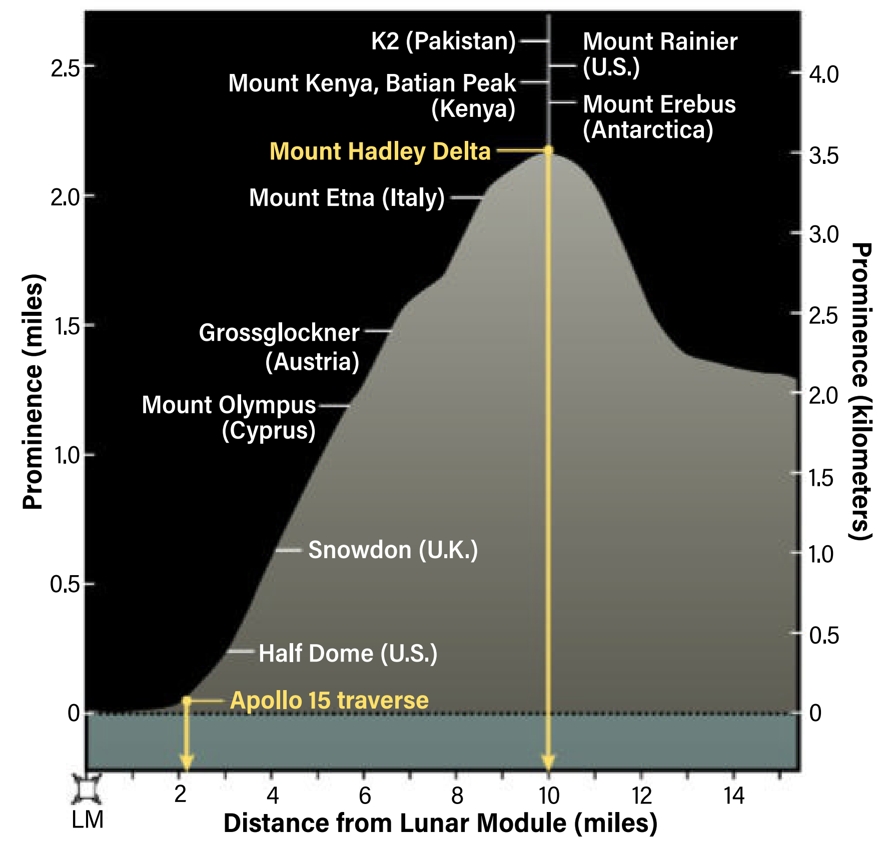
Scott: Yeah, man!

Distinct lineations — both diagonal and horizontal — that the astronauts observed on Mount Hadley are visible in this vertical panorama. Post-flight analysis suggested that most of the lineations were lighting artifacts created by the low Sun and long shadows, though some lineations could also be traces of fractures in the regolith. The image also shows some outcroppings at the base, accompanied by darker bands. NASA/ADAM BOOTLE

Endeavour soars over the Aristarchus Plateau, which contains the gorge of Vallis Schröteri and craters Aristarchus and Herodotus.

MOON MOUNTAINEERING

The Apennines rival some of the great mountains on Earth in terms of their prominence, or how high their summits sit above the surrounding terrain. Here's how Mount Hadley Delta measures up to some famous terrestrial peaks. *ASTRONOMY*: ROEN KELLY, AFTER NASA/GSFC/ARIZONA STATE UNIVERSITY



IRWIN: Yes, you have rear steering.
SCOTT: OK. But I don't have any front steering.

Despite cycling some of the rover's circuit breakers, they couldn't activate front steering. Nevertheless, they took off to the southwest using only rear steering, heading toward the rim of the Hadley Rille. They followed the canyon around to their first station — Elbow Crater, about 1.7 miles (2.7 km) from the LM, hitting top speeds of 7.5 mph (12 km/h). But they couldn't help but notice interesting samples as they sped across the terrain.

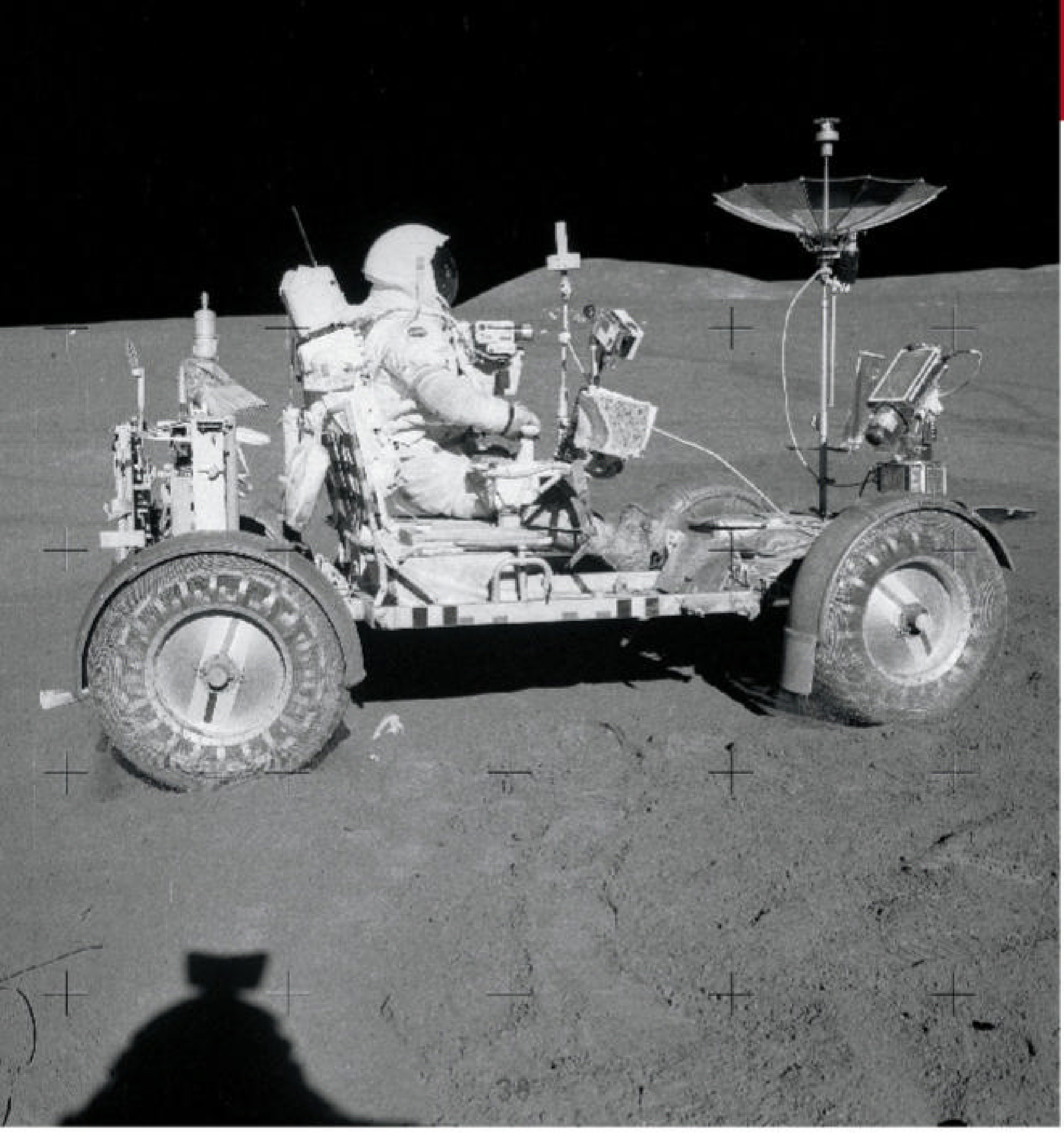
SCOTT: It feels like we need the seatbelts, doesn't it, Jim?
IRWIN: Yes, really do. [...] Boy, it really — really bounces, doesn't it?
SCOTT: Well, I think — there's sort of a — the rear end breaks out at about 10 to 12 clicks [km/h].
ALLEN: Roger, Dave, it sounds like it's like steering a boat, with the rear steering and the rolling motion.
SCOTT: Yes, that's right. It sure is. Hey, here's a good fresh one [crater] right there —
IRWIN: Yes, I was looking at that one at 1 o'clock to us right now. Very fresh angular block of lighter albedo material on the south rim. [...]
SCOTT: *[Laughs.]* Man, this is really a rocking-rolling ride, isn't it?
IRWIN: Never been on a ride like this before.
SCOTT: Boy, oh, boy! I'm glad they've got this great suspension system on this thing. Boy.

The pair pulled up to Elbow Crater and began collecting samples, depositing them into collection bags. Scott and Irwin could barely contain their enthusiasm, even when Allen gently directed them to the next stop on their itinerary, St. George Crater, about 2,000 feet (600 m) away at the base of the Apennine Front.

SCOTT: OK, Joe, you want us to press on up to St. George [Crater]?
ALLEN: That's affirmative, guys. Move on.
IRWIN: OK, Dave.
SCOTT: OK. We're on the way. Oh, boy! This traveling! This is great sport, I'll tell you.
IRWIN: The sandpile [training area at Kennedy Space Center] was never like this.
SCOTT: Yeah, man. I wish we could just sit down and play with the rocks for a while. Look at these things! They're shiny, sparkly! Look at all these babies here — gosh! Man!
IRWIN: Come on, Dave. There'll be a lot of them, let's get back.
SCOTT: Can't resist it. [Let's] go find something neat in St. George.

And they did.

SCOTT: There is one boulder! Very angular, very rough surface texture. Looks like it's partially... Well, it's got glass on one side of it with lots of bubbles, and they're about a centimeter across. And one corner of it has got all this glass covering on it. Seems like there's a linear fracture through one side. It almost looks like that might be a



FAR LEFT: The lunar rover kicks up some dust as Scott maneuvers it at the beginning of their second lunar excursion. His right hand is on the T-shaped handle used to steer the vehicle. Just in front of his hand is a traverse map that shows the Hadley Rille along its western edge and the cratered terrain to the east.

ABOVE LEFT: In the foreground of this image taken on the lower slopes of Mount Hadley Delta, Scott has placed his tongs on a boulder for scale. In the background, the rover leans on the 18° slope somewhat precariously, with one wheel off the ground.

BOTTOM LEFT: Scott reaches for a hammer atop a boulder near the Hadley Rille at Station 9A. His left hand is holding a sample bag with at least one sample in it.

contact — it is! Within the rock. It looks like we have maybe a breccia *[a collection of rock fragments cemented together]* on top of a crystalline rock. It's sort of covered with glass — I can't really tell. […]

IRWIN: It looks fairly recent, doesn't it, Dave?

SCOTT: Yes, it sure does! It sure does! And I can see underneath the upslope side, whereas, on the downslope side, [the soil]'s piled up.

That suggested the rock had been blown out by a meteorite impact and dug into the soil as it came to rest.

SCOTT: Boy, that is really something. Hey, let's get some good pictures of that before we disturb it too much. […]

ALLEN: Roger, Dave and Jim. […] And it probably is fresh; probably not older than three and a half billion years.

SCOTT: Can you imagine that, Joe? Here sits this rock, and it's been here since before creatures roamed the sea in our little Earth.

Next, Scott tried to break off a chunk of it.

SCOTT: OK. Let's try the old hammer. Bring me a couple of bags here, old buddy.

IRWIN: Yeah. Standing by.

Scott began hammering away at the boulder.

SCOTT: *[Laughs.]* Man.

IRWIN: Get a good one?

SCOTT: No.

IRWIN: Pull hard.

SCOTT: Ah, is that hard!

IRWIN: Well indurated.

SCOTT: Wowee. Ah! Ah! *[The sound of hammer blows are audible, conducted through his suit.]* […]

IRWIN: Hey, you're knocking off a few fragments.

SCOTT: Yeah.

IRWIN: Probably the best you're going to be able to do.

SCOTT: Ah! After all that instruction I got.

IRWIN: Dave, I think, up on top here, if you hit it, it will break.

SCOTT: Yeah, right here?

IRWIN: Right there. Yeah. *[Pause.]* Yeah, it's coming loose. *[Pause.]* Yeah.

SCOTT: There it is, I got it. Oh, oop. *[Softly.]* There. That's it, right there.

IRWIN: Boy, that rock is really ready to roll!

SCOTT: There it is.

IRWIN: Yeah, good show.

* * *

The next day started auspiciously: The rover's front steering was suddenly — inexplicably — functional. This made the drive to Spur Crater, some 2.1 miles (3.4 km) south, much easier for Scott.

Geologists hoped that by exploring the lower slopes of the Apennines, the astronauts might encounter ancient samples dating to the era before the Moon's major basins, or mare, had been filled with lava. This primordial material could shed light on the origins of both the Moon and Earth.

They were rewarded: Inside the rim of Spur Crater, they spotted a gleaming rock that became the most famous Apollo sample of all, dubbed the Genesis Rock.

ALLEN: Dave and Jim, […] is it your impression that you are sampling on the ejecta blanket of Spur Crater, now?

SCOTT: Yes, sir — probably from the deepest part, because we're right on the rim.

ALLEN: Sounds good!

SCOTT: OK, [bag number] 195. Wouldn't you agree with that, Jim?

IRWIN: Yeah. Yes, sir.

SCOTT: OK. Now let's go down and —

IRWIN: Get that unusual one?

SCOTT: Get that unusual one. *[Pause.]* Here's some dense… And there's another unusual one. Look at the little crater here, and the one that's facing us. There is a little white corner to the thing. […] OK, there's a big boulder over there down-Sun of us, that I'm sure you can see, Joe, which is gray. And it has some very outstanding gray clasts and white clasts, and oh, boy, it's a beaut! We're going to get ahold of that one in a minute.

IRWIN: OK, I have my pictures, Dave.

SCOTT: OK, let's see. What do you think the best way to sample it would be?

IRWIN: I think probably… Could we break off a piece of the clod underneath it? Or I guess you could probably lift that top fragment right off.

SCOTT: Yeah. Let me try.

As Scott leaned into it, he thought it was a white clast breccia — until a reflection caught his eye, and he realized it was something much rarer.

SCOTT: Yeah. Sure can. And it's a — a white clast, and it's about —

IRWIN: Oh, man!

SCOTT: Oh, boy!

IRWIN: I got —

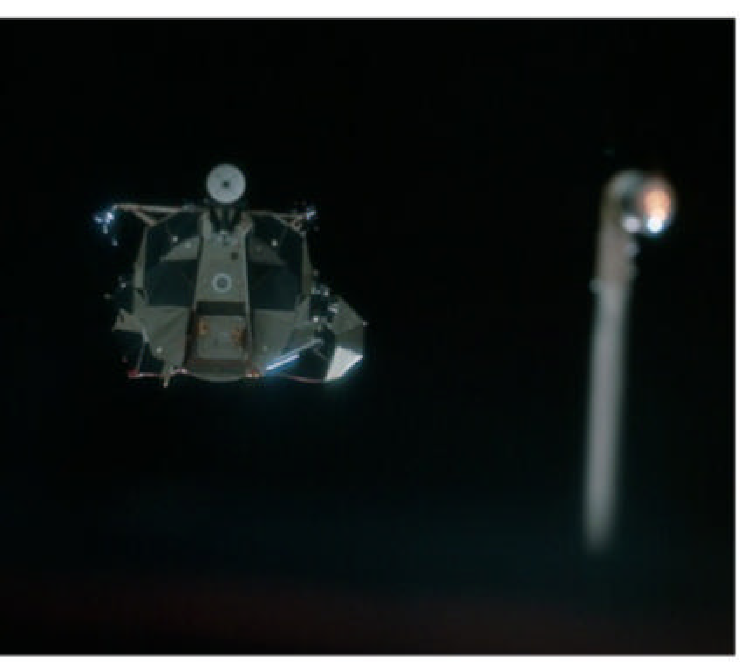
SCOTT: Look at that.

IRWIN: Look at the glint!

SCOTT: Ah…

IRWIN: Almost see twinning *[a symmetrical crystal pattern]* in there!

SCOTT: Guess what we just found.



Worden took this image of the Lunar Module *Falcon* out his window as it rendezvoused and prepared to dock with *Endeavour.*

ABOVE: When Scott and Irwin found the Genesis Rock, it was curiously perched on a pedestal of soil. In this image, the rock itself is the white object on the right side of the lunar dirt pile.

RIGHT: Scott works at the rover at Station 9A at the rim of Hadley Rille, which snakes through this image from right to center. Mount Hadley Delta looms in the background; St. George Crater is at upper right. NASA/DAVID HARLAND

[Laughs.] Guess what we just found! I think we found what we came for.

IRWIN: Crystalline rock, huh?

SCOTT: Yes, sir. You better believe it.

ALLEN: Yes, sir.

SCOTT: Look at the plage *[plagioclase, a type of crystalline formation]* in there.

IRWIN: Yeah.

SCOTT: Almost all plage.

IRWIN: *[Garbled.]*

SCOTT: As a matter of fact — *[laughs]* Oh, boy! I think we might have ourselves something close to anorthosite, 'cause it's crystalline, and there's just a bunch… It's just almost all plage. What a beaut.

IRWIN: That is really a beauty. And, there's another one down there!

SCOTT: Yeah. We'll get some of these.

ALLEN: Bag it up!

SCOTT: Ah! Ah!

IRWIN: Beautiful.

SCOTT: Hey, let me get some of that clod there. No, let's don't mix them. Let's make this a special — why — I'll zip it up.

IRWIN: OK.

SCOTT: Make this bag, 196, a special bag.

ALLEN: Yes, sir.

SCOTT: Our first one. *[Pause.]* Don't lose your bag now, Jim. *[Irwin laughs.]* Oh, boy!

The Genesis Rock was an instant media sensation. Although it was not, as first thought, a piece of primordial lunar crust, at 4.1 billion years old, it was one of the oldest samples found during the entire Apollo program.

* * *

Over the course of the first two days, Scott and Irwin encountered persistent problems using the all-new power drill, struggling to exert enough pressure for it to make headway when planting probes to measure the Moon's internal heat. The issues came to a head on the morning of their third day on the surface, when they were supposed to retrieve a core sample. Although they eventually succeeded, the delays forced them to cut their third EVA short and forgo exploring the North Complex of craters.

Nevertheless, all the mission's science objectives had already been achieved. The astronauts capped their lunar exploration with a short jaunt in the rover over to the rim of Hadley Rille to collect samples. The rover had more than proved its worth, covering 17.5 miles (28.2 km) over 18 hours and 37 minutes of EVA — a new duration record.

Scott: What do you see there, Endeavour?

Worden: Sure see a nice-looking Falcon coming home to roost.

Scott: Roger.

A crescent Earth rises over the wall of Humboldt Crater in this shot taken by Worden.

Shortly after returning to the LM, Scott and Irwin lit the engine of Falcon*'s ascent stage and flew to a rendezvous with* Endeavour *and Worden, who had been keeping busy in lunar orbit with an extensive photography campaign.*

On the 10th day of the mission, Houston sprang a surprise over the radio — the voice of their geology tutor Leon Silver greeted the astronauts, kicking off the first and only direct conversation between a geologist and a crew during the Apollo missions.

SILVER: Hey, Dave. You've done a lovely job. You just don't know how we're jumping up and down, down here.
SCOTT: Well, that's because I happened to have had a very good professor.
SILVER: A whole bunch of them, Dave.
SCOTT: That's right. As a matter of fact, so many of them, it's just hard to — hard to remember it all. But we sure appreciate all you all did for us in getting us ready for this thing. […] I just wish we had had more time, because, believe me, there is an awful lot to be seen and done up there.
SILVER: Yes. We think you defined the first site to be revisited on the Moon. […]
SCOTT: I hope someday we can get you all up here, too. I think we really need to have some good professional geologists up here. As a matter of fact, good professional scientists of all disciplines, not only in lunar orbit, but right on the surface, because you all would just really have a field day, where — with your backgrounds and what you know. There's just so much to be gained up here.

* * *

The crew completed one more task before they left lunar orbit: deploying a small, 78-pound (36 kilograms) probe that had tagged along in the SM. This "subsatellite" would carry out space physics experiments and take measurements of the lunar environment. Then they fired the SM's engine to start their journey back to Earth.

The next day, Worden performed a brief EVA to retrieve film canisters from the SM's cameras from his imaging campaign, clambering out of Endeavour *and along handholds on the SM in the first ever deep-space spacewalk.*

On Aug. 7, 1971, as Apollo 15 barreled into Earth's atmosphere before splashing down at 3:45 P.M. CDT some 330 miles (530 km) north of Honolulu, the astronauts' thoughts of the Moon melted away. On previous missions, moonset — the crews' final glimpse of the Moon as it slipped over the horizon — was a highlight of reentry. But for the astronauts of Apollo 15, it was our home planet that caught their gaze.

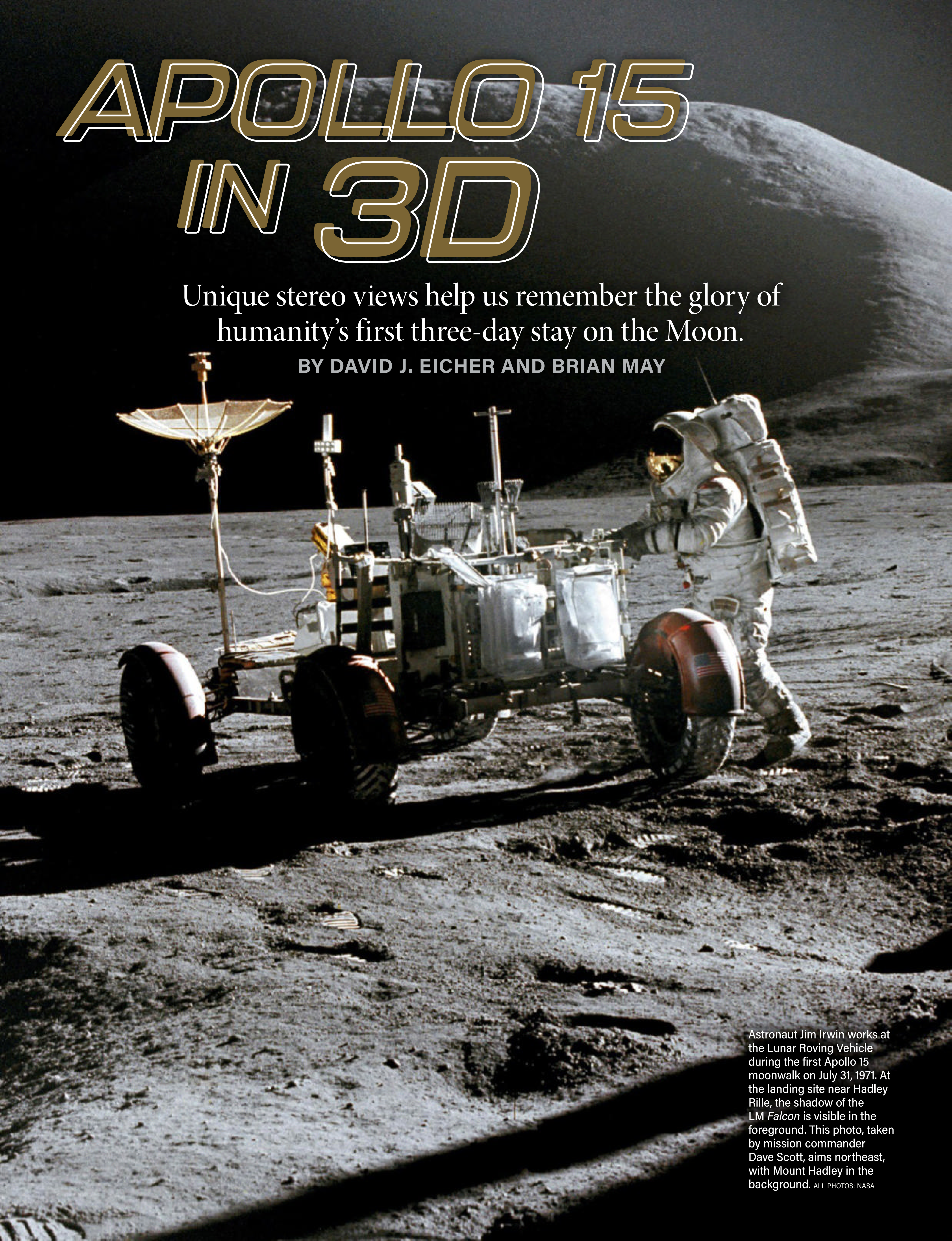
WORDEN: Oh, that's the Earth down there, baby.
IRWIN: Can you see it?
SCOTT: Sure as hell can. Yes, siree, I hope to tell you. […]
WORDEN: Oh, yes. Hey — oh, man, are we moving, too! Son of a gun! Sheeoo!
SCOTT: Yes, indeedy. You ought to be able to see it out the — out the hatch window.
WORDEN: Oh my, I sure can. Sure a lot of mountains down there. How about that?
IRWIN: S---, I think that's Alaska out there. That would be right, wouldn't it?
WORDEN: Yes. Keep an eye out for the Moon.
SCOTT: Yes, keep an eye out for the Moon.
WORDEN: We've done it. Oh, we've missed it. […]
SCOTT: Oh, Al —
WORDEN: We were too busy watching the Earth.
SCOTT: Why don't you pay attention to what you're doing there?
WORDEN: Too busy watching the Earth.

Mark Zastrow *is senior editor of* Astronomy.

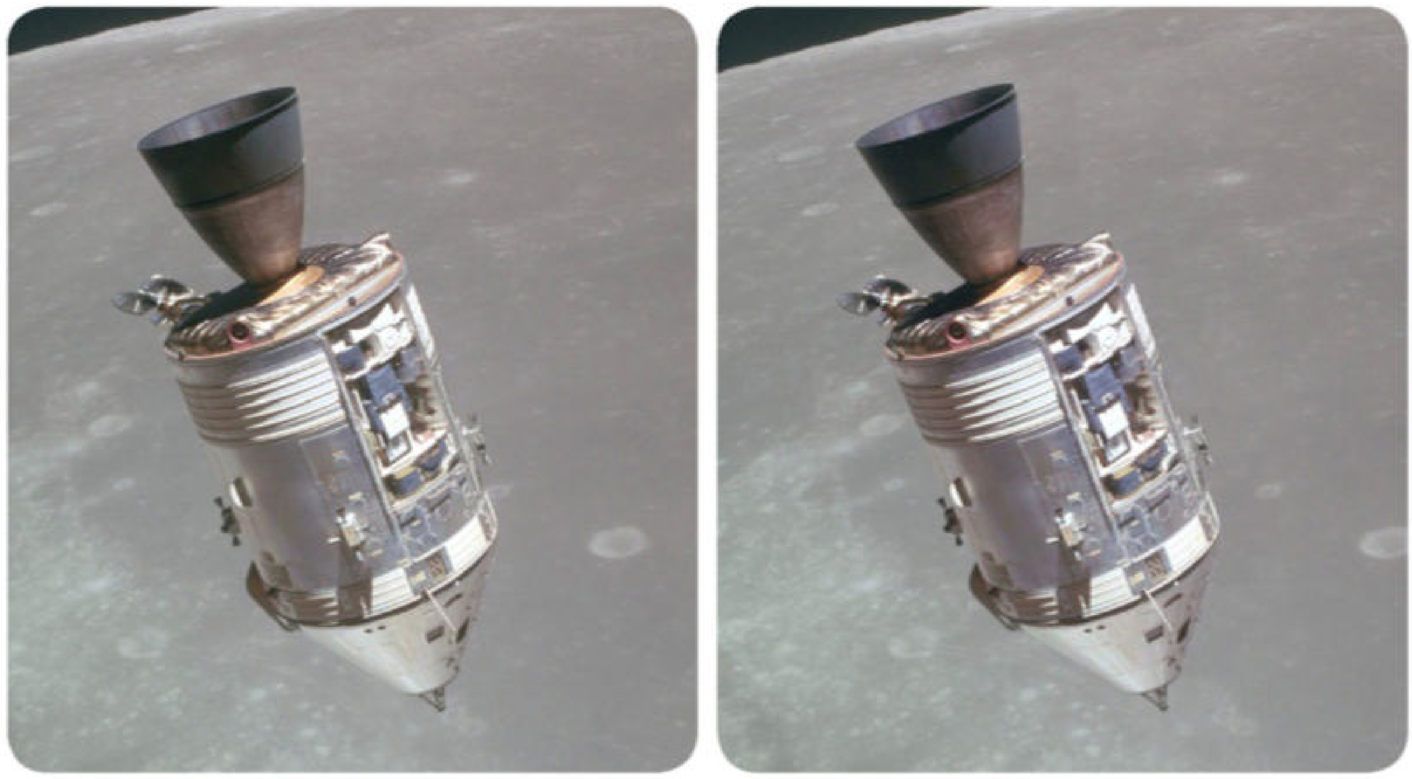
APOLLO 15 IN 3D

Unique stereo views help us remember the glory of humanity's first three-day stay on the Moon.

BY DAVID J. EICHER AND BRIAN MAY



Astronaut Jim Irwin works at the Lunar Roving Vehicle during the first Apollo 15 moonwalk on July 31, 1971. At the landing site near Hadley Rille, the shadow of the LM *Falcon* is visible in the foreground. This photo, taken by mission commander Dave Scott, aims northeast, with Mount Hadley in the background. ALL PHOTOS: NASA



This view of the Apollo 15 Command/Service Module, taken on July 30, 1971, shows the craft in lunar orbit. It offers an opportunity to observe the open bay where panoramic and mapping cameras were located in the final three Apollo mission spacecraft. These cameras enabled sequential stereo coverage of the lunar surface, whereas prior missions captured stereo images only through the Hasselblad cameras operated by astronauts out of the Command or Lunar Module windows.

WITH THE SUCCESS OF Apollo 14 behind them and the near tragedy of Apollo 13 firmly in the past, Apollo's mission planners hiked the length and sophistication of the following mission. Apollo 15 was designed to be the first of the so-called J Missions, a designation in NASA's playbook that constituted longer stays on the lunar surface with an expanded set of scientific goals.

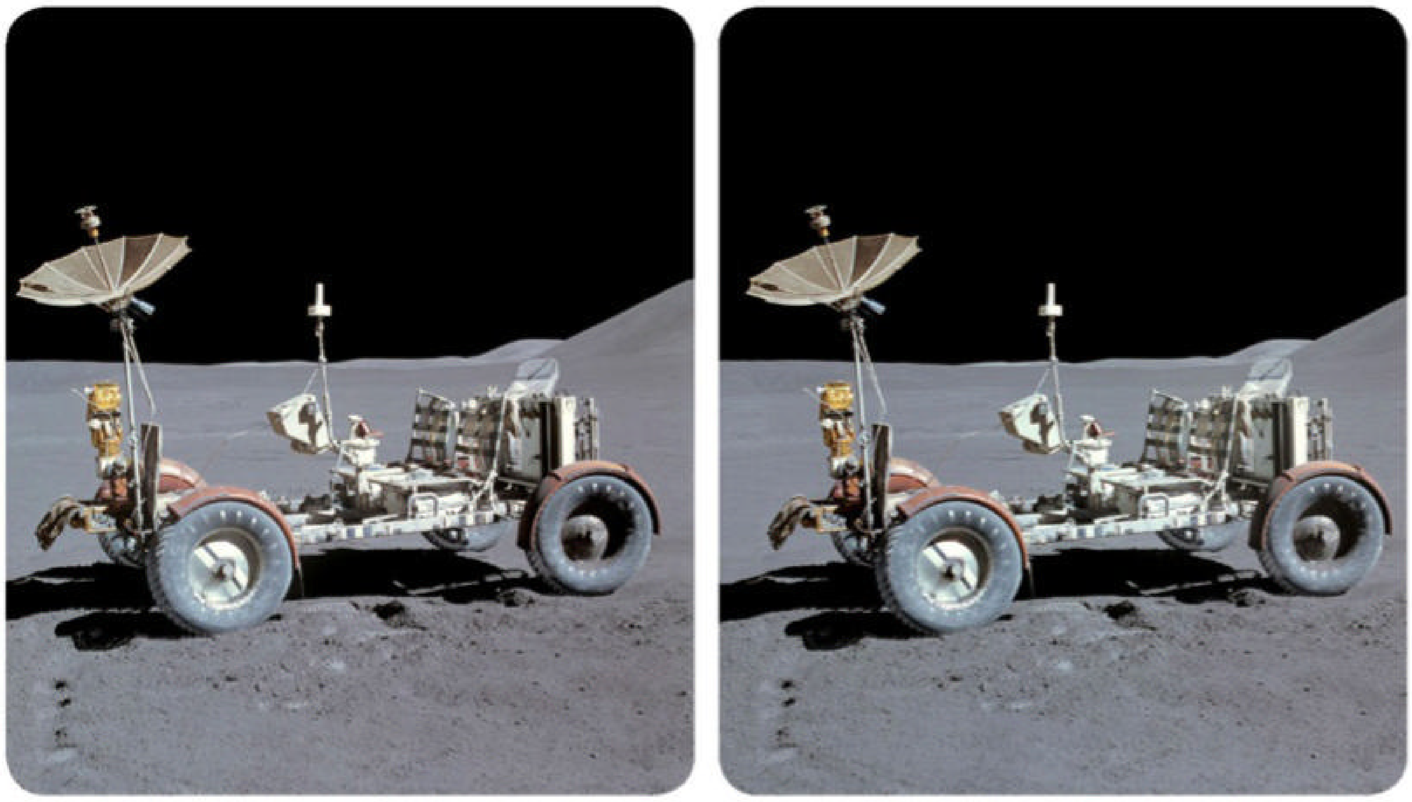
To everyone's excitement, the mission would also be the first to carry along a Lunar Roving Vehicle, the world's most expensive car. Now the amount of lunar territory that could be explored would also expand, as astronauts would not be limited to simply walking in the bulky spacesuits to various destinations. The lunar rover would make driving to areas on the Moon classy and comfortable, and would enable the expansion of scientific studies and also of collecting Moon rock samples from a larger area than was previously possible.

A cultural snapshot

After a six-month period of preparation following Apollo 14, Apollo 15 was scheduled for launch on July 26, 1971. The sweeping social and psychological change that had marked the end of the '60s continued apace. That year in Los Angeles, Charles Manson and his followers were found guilty of the Tate-LaBianca murders and, just a few days later, a major earthquake rocked the area. In the spring, half a million people marched in Washington to protest the Vietnam War, and *The New York Times* began to publish the Pentagon Papers, a classified study of the situation in Vietnam. In New York, workers completed the top floor of the South Tower of the World Trade Center, making it the tallest building in the world.

The world of music and pop culture also raced forward with rapid-fire change. Jimi Hendrix and Janis Joplin were gone, victims of excess; Jim Morrison of The Doors would follow shortly in the summer of 1971. Members of the Beatles experimented with solo careers. In London, a new band formed in 1970 began to rehearse for their first album. It was called Queen, and consisted of Freddie Mercury, Brian May, John Deacon, and Roger Taylor. With that lineup, the band played its first show outside London less than a month before the launch of Apollo 15.

The Apollo 15 crew trained extensively prior to the mission. They are seen here aboard the NASA Motor Vessel *Retriever*, speaking with the lead Underwater Demolition Team swimmer as they practice in the Gulf of Mexico. From left to right are naval officer Fred Schmidt and astronauts Al Worden, Jim Irwin, and Dave Scott.



This perfect stereo view of the Lunar Roving Vehicle at the Hadley Rille landing site was made by Scott during the third Apollo 15 moonwalk. The western edge of Mount Hadley is visible at upper right and the most distant lunar feature in this view is about 16 miles (25 km) away.

The intrepid crew

The Apollo 15 crew consisted of one experienced spaceflight veteran and two rookies. David Scott, the commander, was a 39-year-old Air Force officer and test pilot. Texas-born Scott had been chosen as one of NASA's third astronaut group and subsequently teamed with Neil Armstrong as part of the Gemini VIII mission. He then served as Command Module pilot on Apollo 9 alongside James McDivitt and Rusty Schweickart. Scott's experience would be key for the ambitious narrative expected to come out of Apollo 15. He would be joined by Command Module Pilot Alfred Worden, a 39-year-old Michigan-born man who had been an Air Force pilot and was selected as an astronaut candidate in 1966. The mission's Lunar Module pilot was James Irwin, age 41, who had a background as an aeronautical engineer and Air Force test pilot. Irwin was Pittsburgh-born and was selected in the 1966 group of astronauts along with Worden. The crew's backups consisted of Commander Dick Gordon, Command Module Pilot Vance Brand, and Lunar Module Pilot Jack Schmitt.

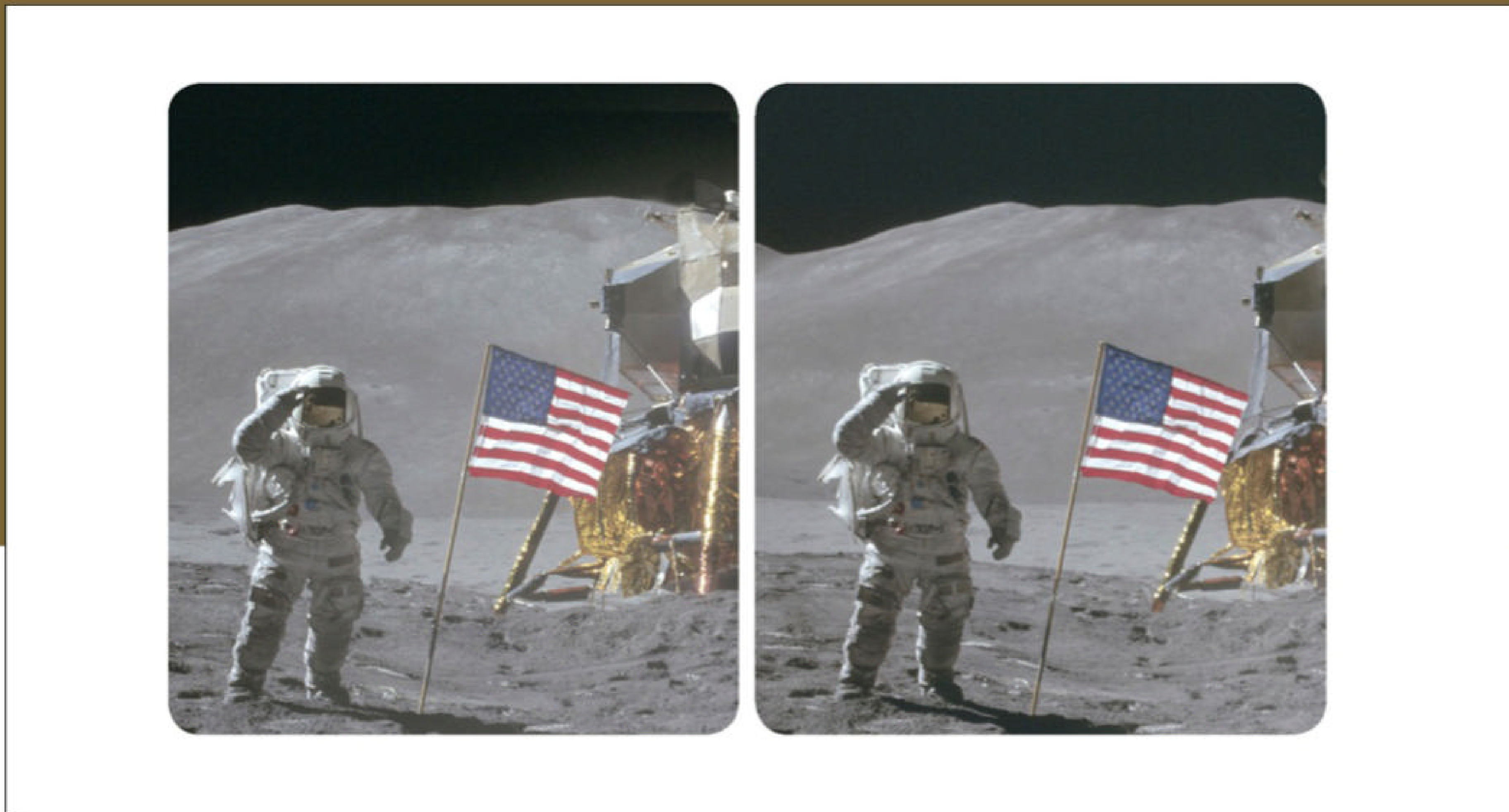
The design for Apollo 15 was ambitious and exciting. The target area was near Hadley Rille, a section of the lunar surface marked by flexure, appearing as a groove cut into the lunar floor. Nearby stands Mons Hadley, a mountainous rise that stretches roughly 13,000 feet (4,000 meters) above the floor below and has a diameter of about 15 miles (25 kilometers). Hadley Rille lies within an area of the Moon known as Mare Imbrium, the Sea of Rains. On the other side of the landing site from Hadley Rille are the lunar Apennine Mountains, a rugged range forming the southeastern rim of Mare Imbrium. The specific area where the spacecraft would land was dubbed Palus Putredinis, the Marsh of Decay.

The Lunar Roving Vehicle

Rather than spending about a day on the lunar surface, as had Apollo 11, 12, and 14, this fourth mission to explore the Moon with humans would allow three days of investigation. Worden would stay within the Command Module, nicknamed *Endeavour*, in lunar orbit. Scott and Irwin would descend to the surface in the Lunar Module (LM), callsign *Falcon*, to explore the Moon, conduct scientific experiments, and collect Moon rocks, all while they drove around.

The lunar rover was the result of a complex engineering project that had been developed for years. Manufactured by Boeing and General Motors, the lunar rover immediately acquired the name "Moon buggy," in a play on "dune buggy." It was a battery-powered four-wheeled cart that would transport not only the astronauts but also ample rock samples and lots of scientific equipment. The concept of a lunar rover originated with Wernher von Braun in the early 1950s. About a decade later, von Braun, now developing NASA's heavy lift rockets with his team at Marshall Space Flight Center in Huntsville, Alabama, again wrote extensively about the need for a lunar roving vehicle.

NASA commenced studies of various roving vehicle concepts at Marshall and some alternatives were far more complex than the final result. Some designs incorporated mobile laboratories, while many designs had sheltered canopies for the astronauts. The original idea was that a second rocket launch could blast a complex, large rover to the Moon. But then the U.S. Congress became concerned with the Apollo budgets, necessitating a single launch for each Apollo mission. This meant that the vehicle had

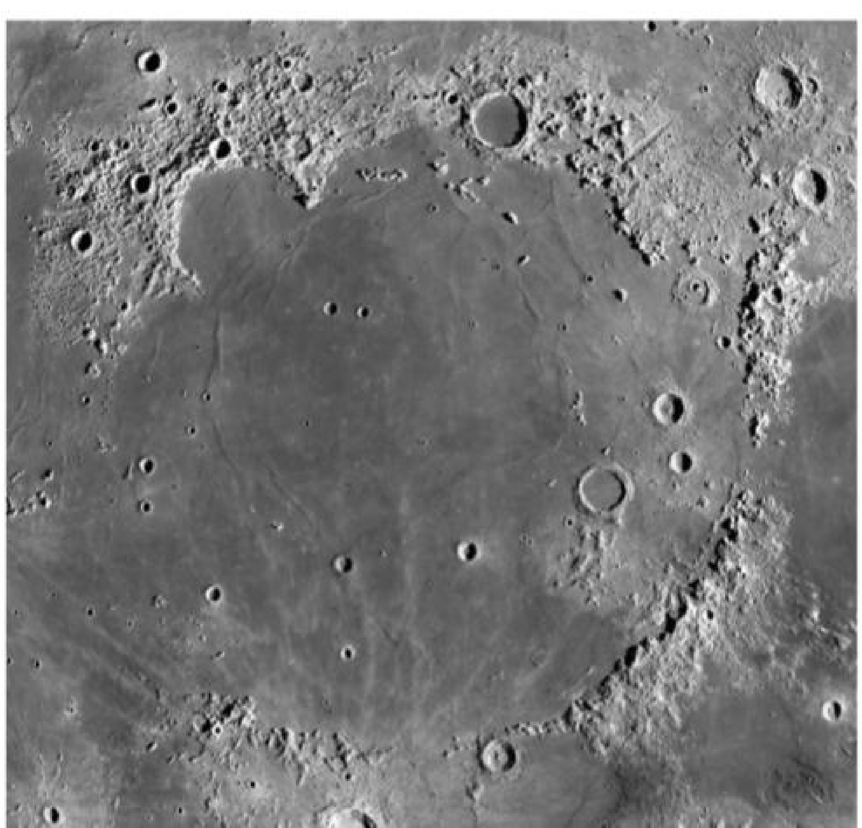


On Aug. 1, 1971, Irwin salutes the U.S. flag on the Moon's surface during the second Apollo 15 moonwalk. The LM *Falcon* stands on the right-hand side of the image and the view is oriented almost due south. In the background, Hadley Delta rises some 11,500 feet (3,500 m) above the surrounding plain. The base of the mountain is about 3.1 miles (5 km) away. The scene was photographed in 3D by Scott.

to fold up and be carried along with the LM, to be unpacked and set up on the Moon's surface.

Between 1965 and 1967, NASA engineers concluded that a vehicle of some type was critical to make the most of lunar studies from the Apollo program. By 1969, they chose the Lunar Roving Vehicle as the winning concept and sanctioned its creation at Marshall, under von Braun's watchful eye. The final development and construction of the lunar rovers took place just before the Apollo 11 landing. Boeing oversaw the project and General Motors, as a subcontractor, provided the wheels, electric motors, and suspension. The final cost of the lunar rover program was $38 million; it provided four cars. Many have since said, with a twinkle in their eye, that the lunar rovers, at $9.5 million each, are the world's most expensive cars — leaving Ferraris and Lamborghinis in the dust!

The lunar rovers really turned out to be a phenomenon that changed the functionality of the Apollo missions. They expanded the range of the lunar explorers, although that range was functionally limited to remain in long-range walking distance of the LM, should a malfunction with the rover occur. These cars had a designed top speed of 8 mph (13 km/h), although during Apollo 17, Gene Cernan reached a velocity of 11.2 mph (18 km/h), making his drive the fastest on the surface of the Moon.



The Lunar Reconnaissance Orbiter made this image of Mare Imbrium, one of the major lunar basins, years after the Apollo missions. It shows the basin as a large circular feature filling most of the frame. The triangle of prominent craters near the right edge of Mare Imbrium consists of Archimedes, Aristillus, and Autolycus. Just below and right of these craters lies Hadley Rille, landing site of Apollo 15.

These lunar vehicles weighed some 460 pounds (210 kilograms) and stretched 10 feet (3 m) from front to back. The frame was constructed from aluminum alloy tubing and the three-part chassis was hinged so it could be folded inside the LM and unpacked and set up on the Moon's surface. The two side-by-side seats were made of aluminum tubing and had nylon webbing. An armrest separated the seats and each had footrests. The wheels consisted of a spun aluminum hub with tires made of steel strands woven together and coated by zinc, then covered with titanium chevrons to help achieve maximum traction on the powdery lunar surface.

Each wheel on the vehicle had its own electric drive, and the vehicle could be maneuvered by front and rear steering motors. Front and rear wheels could turn in opposite directions for maximum maneuverability, or they could be decoupled to provide specific aid in steering and traction. The energy to make this package move came from two silver-zinc potassium hydroxide batteries, each with 36 volts, that powered the drive and

Fallen Astronaut is an aluminum sculpture made by Paul Van Hoeydonck and left on the lunar surface by Scott and Irwin. It commemorates their astronaut and cosmonaut colleagues who died in service.

steering motors, and a utility outlet powered the communications equipment and a color TV camera mounted on the rover's front. The whole thing could be controlled with a T-shaped handle by the astronaut driver.

To deploy the rover, the astronauts had to use ropes and cloth tapes to operate pulleys and braked reels. Stored in a bay inside the LM, the rover had to be released by an astronaut who climbed the LM's ladder; his companion could slowly unfold the chassis of the rover using reels and tapes. Next, the rover was moved down from the bay and could be set up on the ground, its rear wheels locking into place. The entire frame could then be brought down and final assembly achieved: The astronauts assembled the final aspects of the seats and footrests, switched on the vehicle's electronics, and the car was ready for a lunar test drive.

Getting underway

With the rover packed along with everything else in the mighty Saturn V rocket, the crew of Apollo 15 prepared for launch on July 26. In midmorning, the rocket shot skyward and the mission was underway. The launch did not go flawlessly, however. The first stage did not completely shut off on time, briefly raising the possibility of the first stage engines colliding into the second stage boosters, which would have aborted the mission. Exhaust from the second stage engines also damaged the onboard telemetry package. Despite these initial concerns, the rocket performed adequately and lifted the spacecraft into an Earth parking orbit. After some two hours, the third stage ignited and sent the spacecraft shooting toward the Moon.

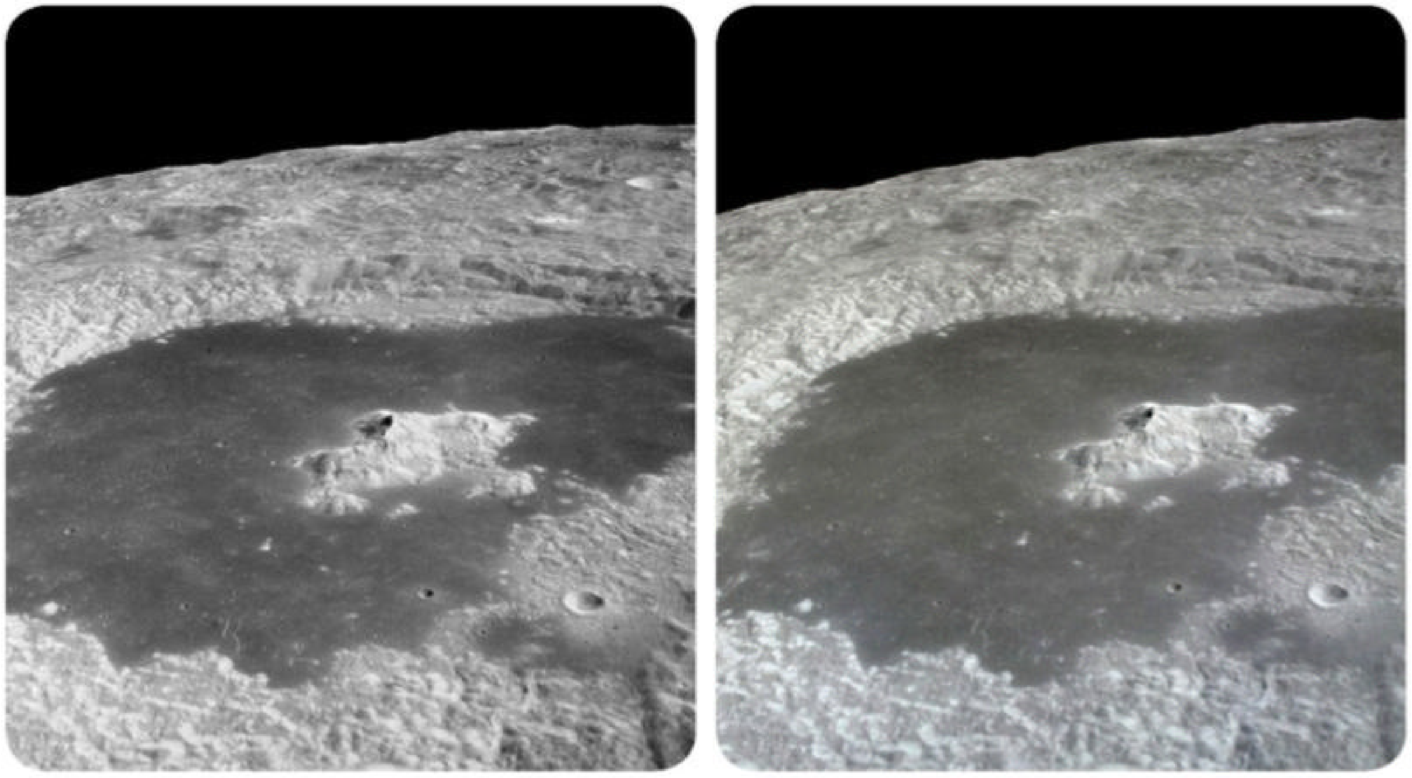
Following the three-day cruise to the Moon, the spacecraft passed behind the lunar farside and the engine on the Command/Service Module burned for six minutes, placing the spacecraft into the right configuration for a LM landing at Hadley Rille. As they orbited the Moon, gazing down at its gray surface, the astronauts prepared for the undocking of the LM and its descent. On the first attempt to undock the Command/Service Module from the LM, however, the astronauts encountered a glitch. The Command/Service Module had a faulty hatch, it turned out. It was resealed by Worden. The separation then occurred, with Scott and Irwin in the LM and Worden remaining in the Command/Service Module.

The two descending astronauts stood in the tightly packed LM, as had their predecessors, for the slow downward movement. As they fell gradually toward Hadley Rille, the astronauts discovered they were some 3.7 miles (6 km) east of the target landing spot. Scott then took control of the descent and maneuvered *Falcon* further toward the target. The craft gently fell and touched down just

VIEWING 3D IMAGES

There are two ways to view the images printed in 3D. To free view the images with no mechanical assistance, let your eyes relax as you view the photos as though focusing on a point behind them. At first you will see the two images split into four; as your eyes focus at the correct distance, the middle two images will combine to create a single, crisp 3D image. The outer two images will remain on either side of the 3D image and become blurry.

Alternatively, you can use a 3D viewer, such as the Lite OWL viewer designed by Brian May and included with the *Mission Moon 3-D* book, to view images in 3D. Only 5 by 2.5 inches (134 by 64 millimeters) and 0.1 inch (3 mm) thick, the Lite OWL viewer is designed for easily viewing 3D images in books, magazines, modern and vintage stereocards, and even video or other VR content on your smartphone. You can purchase individual Lite OWL viewers separately at **www.MyScienceShop.com**.



Tsiolkovsky Crater on the lunar farside is one of the most popular features in Apollo photography. This portrait was taken by Worden as the Apollo 15 Command Module orbited the Moon. The central peak stands out in stereo like a bright island in the dark sea of the crater floor.

a few hundred yards from the intended site. Irwin announced that a landing probe on one of the legs touched down, establishing contact, and Scott cut the engine. Despite its gentle nature, this descent was faster than previous Apollo missions — faster than a hotel elevator — at some 7 feet (2 m) per second.

"Okay, Houston. The *Falcon* is on the Plain at Hadley," blurted Scott. In a lunar landing first, one of the LM's legs had landed in a small crater, tilting the craft by about 10° from level so the LM appeared skewed in images, but this didn't create a functional problem. Missing the landing spot by a few hundred yards was also not alarming, as the rover would make travel easier.

Rather than exiting the LM quickly, as previous missions had, Scott and Irwin stayed within *Falcon* for the rest of their day to stay on a normal sleep schedule. Before falling asleep, however, Scott photographed the lunar scene from the LM's top docking hatch, standing up and poking his head outside the LM, shooting the surroundings with a 500mm lens. He recognized features the astronauts had studied on maps: the Mons Hadley massif, Mons Hadley Delta (another massif), the Swan Range, the Silver Spur (a rock formation), Bennett Hill, Hill 305, and the North Complex (a group of hills). Scott returned through the hatch and repressurized the LM. Then Scott and Irwin went to sleep.

The first excursion

As the astronauts slept, Houston controllers became concerned with falling pressure readings from the descent stage oxygen tanks in the LM. They let Scott and Irwin sleep, however, and in the end woke them an hour early to switch into a high-telemetry-rate mode. This allowed the controllers to see that a valve was open and the astronauts had lost a little less than 10 percent of their oxygen. But the supply was still more than ample.

With the astronauts awake, they prepared for the first of three long moonwalks. Scott became the seventh human to climb down onto the Moon and said: "As I stand out here in the wonders of the unknown at Hadley, I sort of realize there's a fundamental truth to our nature. Man must explore. And this is exploration at its greatest." Some seven minutes later, Irwin joined him on the lunar surface and the astronauts unpacked equipment stowed into the LM, including the rover. They positioned the TV camera, and then Scott had the privilege of the first drive of a rover on the Moon's surface. He found only the rear-wheel steering was working and the suits didn't bend much when they sat down in the car, making driving a little strained. They reclined backward to ease the strain, which worked reasonably well.

Starting off at about 6 mph (9 km/h), the astronauts began a planned circuit of activities. They drove along Hadley Rille, which made finding targets relatively easy. First, they arrived at Elbow Crater, a 1,115-foot-wide (340 m) depression. The mission now focused on geological activities, collecting samples, and photography. They pressed on a distance of 1,640 feet (500 m) to St. George Crater, a 1.5-mile-wide (2.4 km) pock on the Moon. They did not see the amount of ejecta they had hoped for, which would be geologically intriguing. So instead of spending lots of time there, they moved on to a boulder they noticed in the open, near a tiny crater. Taking samples, they tried to roll the rock and ended up chipping pieces off of it. They used a rake with tines set 0.4 inch (1 centimeter) apart to collect samples of pebbles from the area. They also took core samples by driving tubes down into the powdery lunar surface.

Moving again, Scott and Irwin bypassed a planned stop at Flow Crater

On Aug. 12, 1971, Scott gets a close look at the sample known as Genesis Rock at the Manned Spaceflight Center in Houston, Texas. At left, astronaut Joseph Allen looks on with interest. The whitish rock has been given permanent identification as specimen no. 15415.

On Aug. 7, 1971, the Apollo 15 crew — Scott (saluting), Worden, and Irwin — appear happy to be back on Earth aboard the recovery ship USS *Okinawa* following their successful mission.

because of time constraints, and pressed on toward the LM. They stopped at Rhysling Crater and, on their final push back to the LM, Scott spotted a large piece of vesicular basalt that looked tempting. He stopped the rover, grabbed the rock, and carried it into the rover while Irwin distracted controllers in Houston. Because Scott stalled for time by saying his seatbelt had loosened, this rock is called the Seatbelt Basalt.

At the LM, the duo set up the normal Apollo Lunar Surface Experiments Package, or ALSEP, set of experiments, including a seismometer, magnetometer, solar wind spectrometer, and other instruments. After more than six and a half hours of activity, the weary pair climbed back into the LM, ready to rest after such exertion. Irwin's water bag had not worked properly, so he had gone through the whole surface activity without fluids.

The second moonwalk

Some 16 hours later, on Aug. 1, Scott and Irwin commenced their second extravehicular activity. They would again focus on the Mount Hadley Delta complex, but this time headed directly to a site to the east of the previous day's action. They moved along the planned route but, unexcited by some of the visuals they encountered, skipped some of the planned sites. They took samples from a 3-foot-wide (1 m) crater, finding breccias and porphyritic basalt. Scott then moved to a larger crater but found the rocks inside it too large to sample. Houston asked the pair to dig a trench to study soil characteristics, which Irwin did while Scott photographed the exercise.

They then returned to the rover and drove a long distance to find a 10-foot (3 m) boulder, noticing a greenish hue on it caused by magnesium oxide. The astronauts then traversed to Spur Crater, a 320-foot-wide (100 m) depression that sank 66 feet (20 m) into the lunar ground. They took samples and noticed white mineral veins in some of them, and a greenish hue in the soil that they determined was caused by the gold color of their visors.

Then, in a moment of triumph, they collected what has since become the most famous lunar sample taken from the Moon during any Apollo mission. What was labeled as Lunar Sample 15415 looked initially like a partially crystalline rock, but on further examination, the astronauts saw it was nearly completely plagioclase, a tectosilicate feldspar mineral. At first, they — and scientists who studied this sample — believed the explorers had found a piece of the lunar crust. The media dubbed the sample Genesis Rock. Analysis later showed the rock to be 4.1 billion years old — some half a billion years younger than the Moon's formation. Despite this, it remains a very ancient and captivating sample.

Houston then asked the pair to collect as many small samples as they could. They raked for small samples, collecting many, and Scott struck and fractured a rock with his rake, collecting the pieces. Before they climbed back into the LM, the two attempted to repeat a task that had failed the previous day: drilling holes nearby to facilitate a heat-flow experiment. Unfortunately, their trouble continued. They set up the U.S. flag near the LM and then returned to the interior after an excursion that lasted seven hours and 12 minutes.

The final day

A third moonwalk and drive began with trying to rectify the problems the pair had with drilling holes. They extracted some core samples but continued to be frustrated with the drilling and didn't want to waste too much time focusing on it. They filmed the rover and then traveled to Hadley Rille, arriving at a small crater. Samples collected there were soft; this area is thought to be the youngest explored by moonwalkers. They photographed the rille and looked for exposed bedrock, hoping to find ancient material. In the wall of the rille, they hoped to see layering, indicative of lava flowing over time through Palus Putredinis. Irwin found some exposed bedrock and took samples. Scott found a coarse-grained basalt with large vugs, or cavities. He carted off a football-sized rock that came to be called Great Scott, a 21-pound (9.6 kg) sample.

Back at the LM, with time running out, Scott had one more trick up his sleeve. "Well, in my left hand, I have a feather," he said. "In my right hand, a hammer. And I guess one of the reasons we got here today was because of a gentleman named Galileo, a long time ago, who made a rather significant discovery about falling objects in gravity fields.

Schmidt helps Scott out of the Apollo 15 spacecraft into a life raft during recovery operations on Aug. 7, 1971. The capsule landed some 330 miles (530 km) north of Honolulu, Hawaii. One of the three parachutes failed to deploy properly, but the mishap caused no injuries.

And we thought, where would be a better place to confirm his findings than on the Moon? And so we thought we'd try it here for you. The feather happens to be, appropriately, a falcon feather for our *Falcon*. And I'll drop the two of them here and, hopefully, they'll hit the ground at the same time."

He dropped the two and they hit the lunar surface simultaneously: a win for Galileo once again. Before ending the walk, Scott drove the rover away a distance and planted an object on the lunar surface. It was a sculpture, made of aluminum, created by the Belgian artist Paul Van Hoeydonck. Called Fallen Astronaut, it was a small astronaut figure and was accompanied by the names of American and Soviet explorers who had died in the quest for space. The names were Theodore Freeman, Charles Bassett, Elliott See, Gus Grissom, Roger Chaffee, Ed White, Vladimir Komarov, Edward Givens, Clifton Williams, Yuri Gagarin, Pavel Belyayev, Georgiy Dobrovolsky, Viktor Patsayev, and Vladislav Volkov.

Successful return

After four hours and 50 minutes, Scott and Irwin climbed back into the LM. Two days and 18 hours after they had landed, the astronauts blasted off from the Moon's surface, rejoined Worden, and headed back to Earth. The crew splashed down in the North Pacific on Aug. 7, with 170 pounds (77 kg) of lunar samples in tow.

Apollo 15 had been the most scientifically interesting mission yet. And with the Fallen Astronaut, the anxiety between competitors had now transformed into a bond between fellow explorers.

Astronomy editor **David J. Eicher** *is the author of 25 books on science and history.* **Brian May** *is an astronomer and founding member and guitarist of the legendary rock band Queen.*

This story is adapted from Mission Moon 3-D: A New Perspective on the Space Race*, by David J. Eicher and Brian May, foreword by Charlie Duke, afterword by Jim Lovell, © 2018 by London Stereoscopic Co. and MIT Press, Boston.*

EXPLORE FROM HOME

Mission Moon 3-D: A New Perspective on the Space Race, by David J. Eicher and Brian May (with foreword by Charlie Duke and afterword by Jim Lovell), presents the story of the historic lunar landings and the events that led up to them, told through text and three-dimensional images.

Mission Moon 3-D contains new and unique stereoscopic images of the Apollo Moon landings to show what it was like to walk on the lunar surface. The triumph of the Apollo 11 Moon landing takes center stage, with detailed stories and visually stunning images from the lunar missions that followed. The book includes 150 stereo photos of the Apollo mission and space race — the largest group ever published — and presents photos never seen before in stereo.

The book delivers a comprehensive tale of the space race. New stories appear from the astronauts, including Jim Lovell's anecdotes about the perilous return of Apollo 13.

Mission Moon 3-D also includes a history of the music and special movements of the 1960s and beyond that transformed the world, from Vietnam and Woodstock to Live Aid. Don't miss out on this unique treasure.

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.
BY MARTIN RATCLIFFE AND ALISTER LING

JULY 2021
Planetful nights

A delicate crescent Moon shares the twilight sky with Mercury. A similar sight is available to early risers this month. STEPHEN RAHN

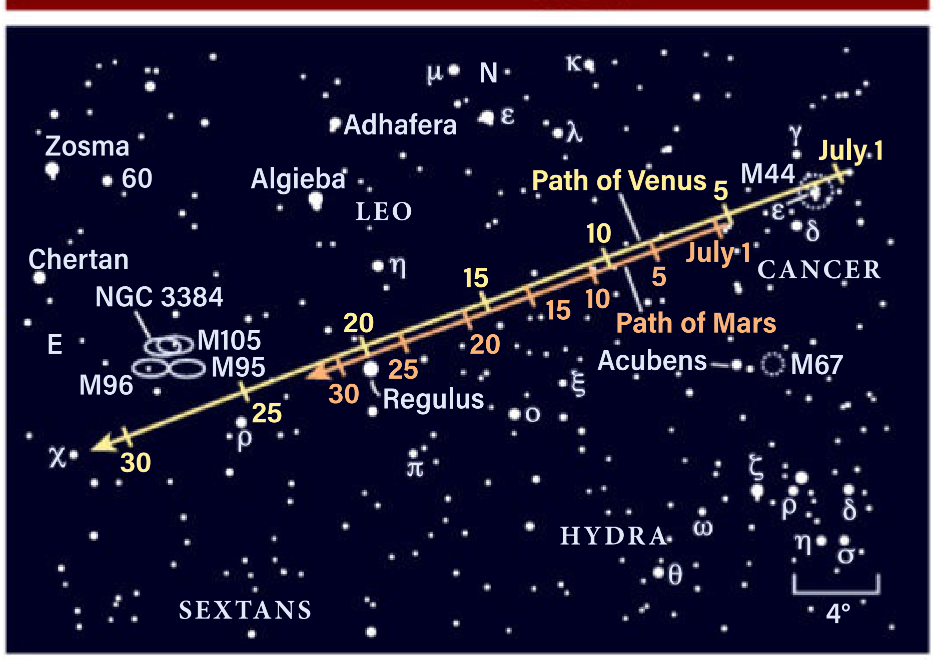
The shorter summer evenings still offer a wide range of planetary events for casual and serious observers alike. Venus dominates the evening sky, while Mars lingers in twilight as well. The midnight sky brings Jupiter and Saturn into view as they approach their best appearance for the year. Binoculars can track down Uranus and Neptune, both of which lie near field stars. Mercury makes an appearance as dawn breaks; see if you can catch it before the Sun bakes the sky blue.

July 1st provides a spectacular view of **Venus**, visible as a brilliant magnitude –3.9 object low in the western sky soon after sunset. Don't miss the opportunity to take a look with a pair of binoculars. If the sky is dark enough and it's not too hazy, you might make out the star cluster popularly known as the Beehive (M44), or Praesepe, in Cancer the Crab. It appears just 1.5° east of Venus. Look also for **Mars**, 7° east of Venus and shining at magnitude 1.8.

An even more spectacular view occurs the next evening, July 2, when Venus lies within the northern regions of M44. Venus sets around 10 P.M. local time; 30 minutes earlier, the twilight glow diminishes the cluster's visibility, but it's worth trying to view or photograph this beautiful scene. The Beehive's brightest stars are 6th magnitude and the cluster's total apparent magnitude is 3.7, so it may only appear as a faint mistiness in twilight. Find a location with a clear western horizon where you can safely set up your telescope for a fleeting — but hopefully perfect — view of the planet apparently embedded in this distant star cluster.

Venus displays an 89-percent-lit gibbous disk through a telescope and spans 11". It crosses into Leo July 11, when a two-day-old crescent Moon joins it in the western sky and Mars and Venus are separated by less than 1°. The following evening (July 12), the Moon appears east of the pair, with Mars nearly 33' due south of Venus. Both planets are visible together in a telescopic field of view, which will show Mars spanning slightly less than one-third Venus' width. Such conjunctions are line-of-sight effects — in reality, Mars lies about 1 astronomical unit

Mars and Venus mingle all month



Mars and Venus share the same region of sky all month, coming closest in mid-July. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY & KELLIE JAEGER

OBSERVING HIGHLIGHT

VENUS sits 0.5° above **MARS** on July 13. Find them in the west after sunset, near the four-day-old Moon.

(the average Earth-Sun distance, or approximately 93 million miles) farther from our planet than Venus, which itself stands 1.4 astronomical units from Earth. (For more on this event, see "Venus and Mars meet up" on page 50.)

Venus is 1.1° north of Regulus, Leo's brightest star, on July 21. It is followed eight days later by Mars. Venus continues across Leo through the last 10 days of the month and spans nearly 13" by the end of July. Mars stands near Regulus on July 28 and 29; it appears slightly northwest of the star on the first evening and slightly northeast the next night. They are closest on the 29th as seen from the Americas, separated by 38'.

Saturn is within a month of its Aug. 2 opposition, and rises around 10 P.M. local time on July 1. It's well placed — more than 16° high at local midnight in the southeast — and reaches the meridian around 3 A.M. local time, making this the best time to view the ringed planet in early July. By the end of the month, it reaches the meridian about two hours earlier.

Occasionally Saturn passes a deep-sky object, but the brightness contrast makes viewing difficult. For example, Saturn slides 1' due east of the magnitude 14 galaxy IC 1339 on July 4/5. Photographing the pair

— Continued on page 38

RISING MOON | To the pole!

WILL YOU BE STRUCK BY LUNAR GOLD near Full Moon? As it tracks low in the sky, blue light gets scattered away by the longer path through Earth's atmosphere, producing a warm yellow glow. You may additionally notice something unusual: Mare Crisium on the eastern limb almost looks like it's on the equator. And there's all this "extra" light-hued terrain near the north pole!

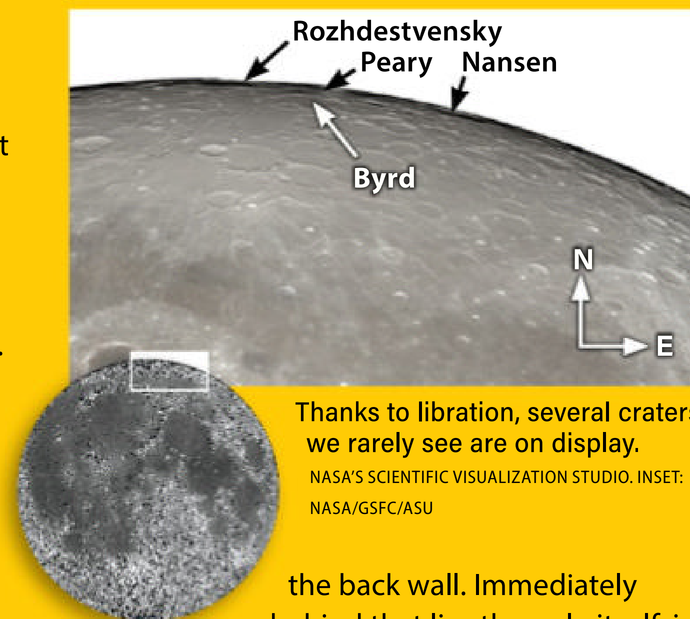
The Moon slowly bobs up and down across the ecliptic — the imaginary plane of our solar system — and hits the lowest point on the 22nd. From our earthbound perspective, we get to see a little past the top of Luna's head and down the farside — astronomers call this a northern libration. If you're up for a little adventure, let's embark on a trek to the north pole.

Features close to the lunar north pole are named for great explorers of past centuries. Two main ones are named for American adventurers Richard Byrd and Robert Peary. The brilliantly rayed crater Anaxagoras is useful as a reference marker. Smack below the northern limb you can identify Byrd as the larger, flat, fully illuminated oval.

Nicely sunlit is Byrd's back wall, almost indistinguishable from Peary's outer southern flank. And what a fantastic 3D view we get, thanks to the shadow placement. Peer past Peary's parapets into its partially shadowed crater, right up to the back wall. Immediately behind that lies the pole itself, in shadow. But there's more: The outer rim of Rozhdestvensky is lit up. Named for a Soviet physicist, this feature is at 87° latitude on the lunar farside! Off to the east (right) down the limb a bit is another light-dark pair: the walls of Nansen, named after the Norwegian explorer.

The up-down cycle of 27.2 days leaves us one more chance Aug. 21st and 22nd, before it drifts out of sync with the period of the Moon's Full phase.

Lunar north pole



Thanks to libration, several craters we rarely see are on display. NASA'S SCIENTIFIC VISUALIZATION STUDIO. INSET: NASA/GSFC/ASU

METEOR WATCH | Scan the horizon

Southern Delta Aquariid meteors

The Southern Delta Aquariids' radiant is 10° west of 3rd-magnitude Skat. The best time to spot meteors is two to three hours before dawn.

SOUTHERN DELTA AQUARIID METEORS

Active dates: July 12–Aug. 23
Peak: July 30
Moon at peak: Waning gibbous
Maximum rate at peak: 25 meteors/hour

METEOR SHOWERS ARE FICKLE THINGS. We can only predict expected rates per hour, which are heavily dependent on your location, the amount of street lighting and moonlight, and the height of the radiant above the horizon.

All this means that predicted rates are usually tempered a great deal. Such is the fate of the Southern Delta Aquariids, which can produce 20 to 25 meteors per hour on a good night with the radiant overhead. But for those at mid-northern latitudes, the radiant climbs only to 30° in altitude, reducing the expected number to 10 per hour. A waning gibbous Moon provides a lot of light on the peak date of July 30, limiting visible meteors to the brightest ones.

Yet one brilliant meteor is truly memorable and it's why observers enjoy any shower. Jupiter sits 4° north of the radiant, which rises before local midnight. The shower is active from July 12 to Aug. 23 — a wide range, allowing observers to look for shower members when the Moon is out of the way.

STAR DOME

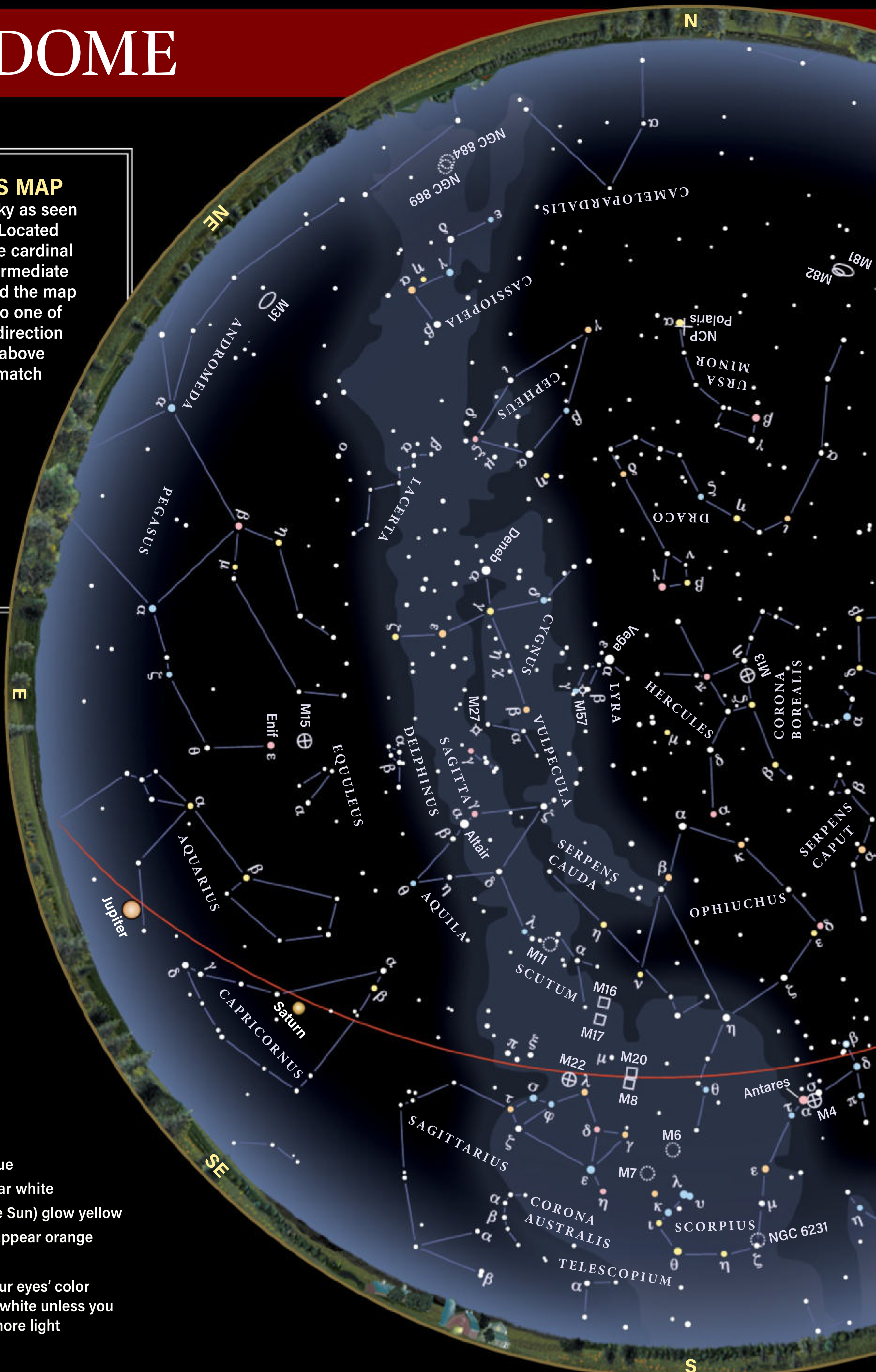
HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight July 1
11 P.M. July 15
10 P.M. July 31

Planets are shown at midmonth



MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

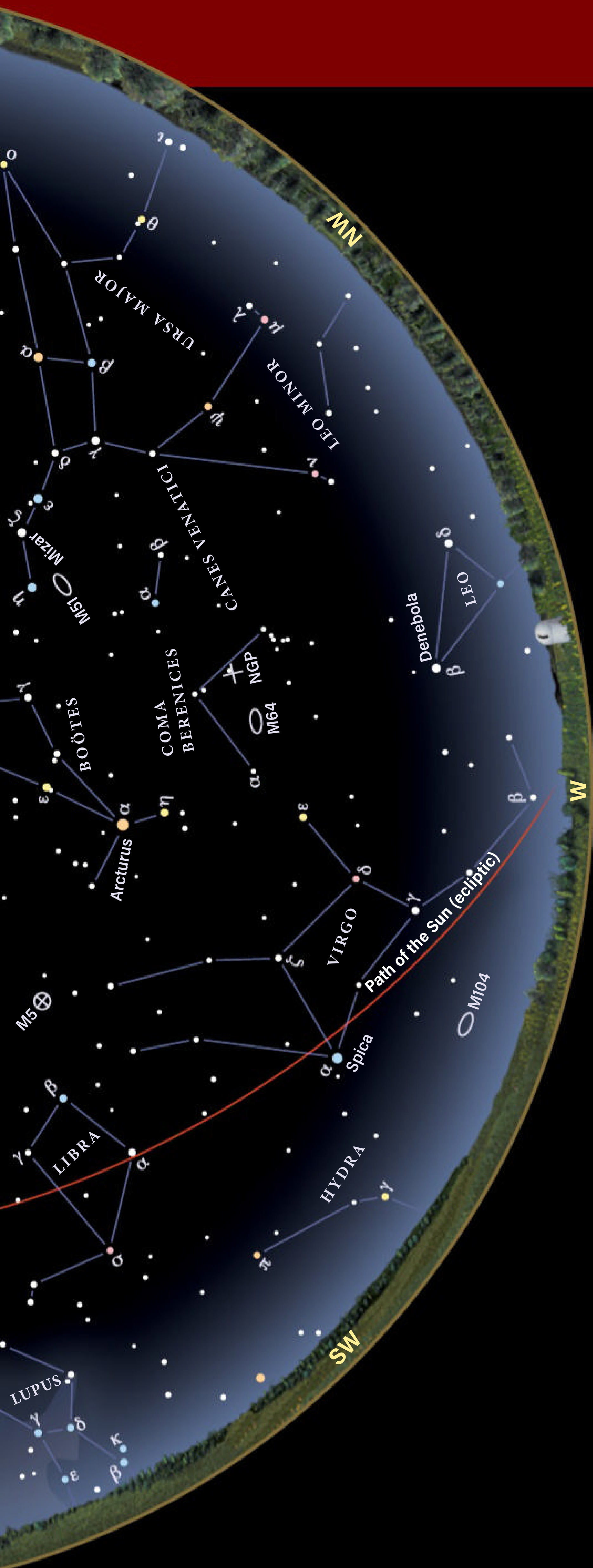
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



JULY 2021

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
				1	2	3
4	5	6	7	8	9	10
11	12	13	14	15	16	17
18	19	20	21	22	23	24
25	26	27	28	29	30	31

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 Last Quarter Moon occurs at 5:11 P.M. EDT

4 The Moon passes 2° south of Uranus, 11 A.M. EDT

Mercury is at greatest western elongation (22°), 4 P.M. EDT

5 The Moon is at apogee (251,867 miles from Earth), 10:47 A.M. EDT

Earth is at aphelion (94.5 million miles from the Sun), 6 P.M. EDT

8 The Moon passes 4° north of Mercury, 1 A.M. EDT

9 New Moon occurs at 9:17 P.M. EDT

12 The Moon passes 3° north of Venus, 5 A.M. EDT

The Moon passes 4° north of Mars, 6 A.M. EDT

Mars is at aphelion (154.9 million miles from the Sun), 8 P.M. EDT

13 Venus passes 0.5° north of Mars, 3 A.M. EDT

17 First Quarter Moon occurs at 6:11 A.M. EDT

Asteroid Hebe is at opposition, 7 A.M. EDT

Pluto is at opposition, 7 P.M. EDT

18 Asteroid Pallas is stationary, 4 P.M. EDT

21 The Moon is at perigee (226,503 miles from Earth), 6:24 A.M. EDT

Venus passes 1.2° north of Regulus, 3 P.M. EDT

23 Full Moon occurs at 10:37 P.M. EDT

24 The Moon passes 4° south of Saturn, 1 P.M. EDT

25 The Moon passes 4° south of Jupiter, 9 P.M. EDT

27 The Moon passes 4° south of Neptune, 2 P.M. EDT

29 Mars passes 0.7° north of Regulus, noon EDT

30 Southern Delta Aquariid meteor shower peaks

Asteroid Victoria is at opposition, 9 A.M. EDT

31 Last Quarter Moon occurs at 9:16 A.M. EDT

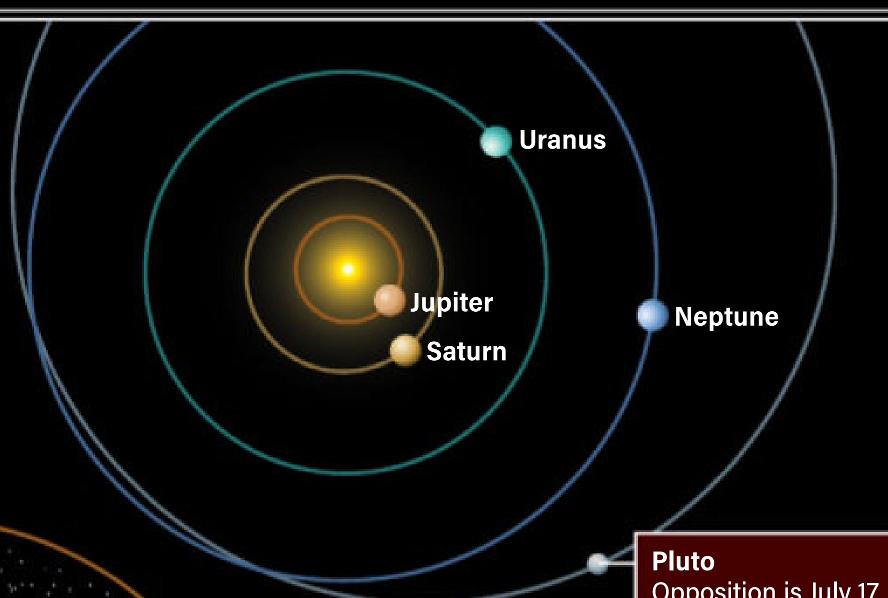
The Moon passes 1.8° south of Uranus, 8 P.M. EDT

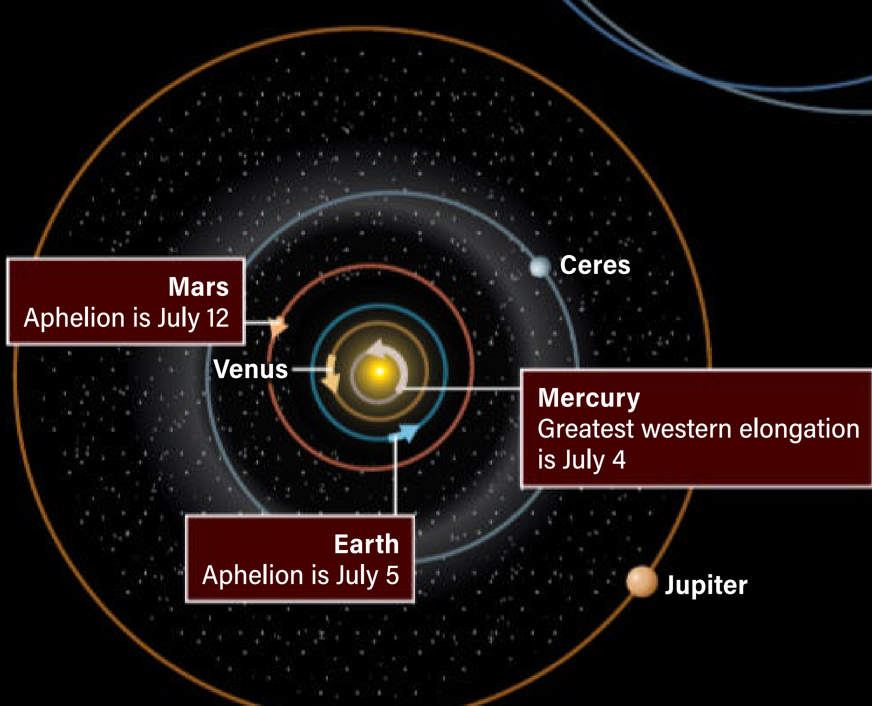
PATHS OF THE PLANETS

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

THE PLANETS IN THEIR ORBITS

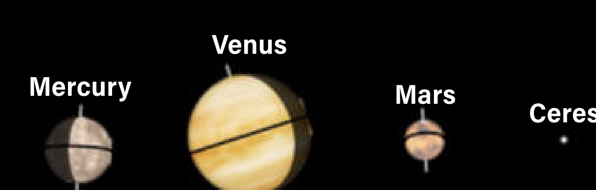
Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.





THE PLANETS IN THE SKY

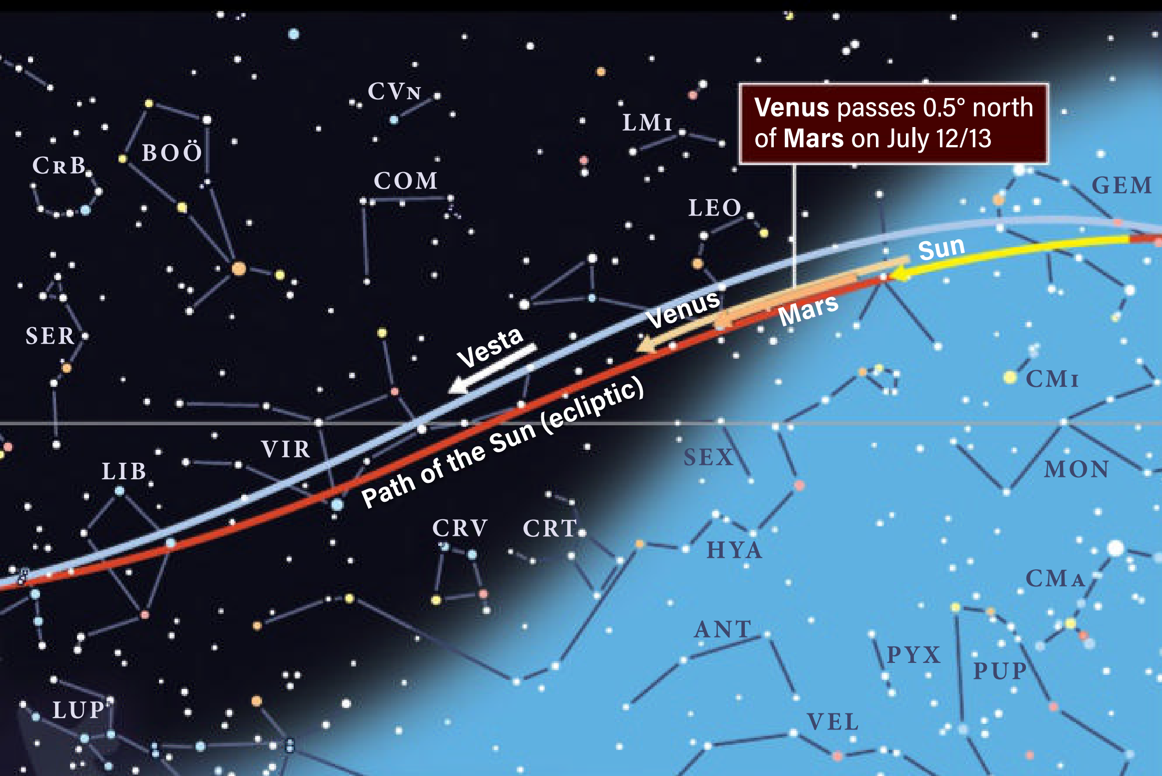
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.



PLANETS	MERCURY	VENUS
Date	July 15	July 15
Magnitude	–0.6	–3.9
Angular size	6.3"	11.8"
Illumination	66%	87%
Distance (AU) from Earth	1.073	1.418
Distance (AU) from Sun	0.331	0.720
Right ascension (2000.0)	6h19.5m	9h36.7m
Declination (2000.0)	22°26'	15°58'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

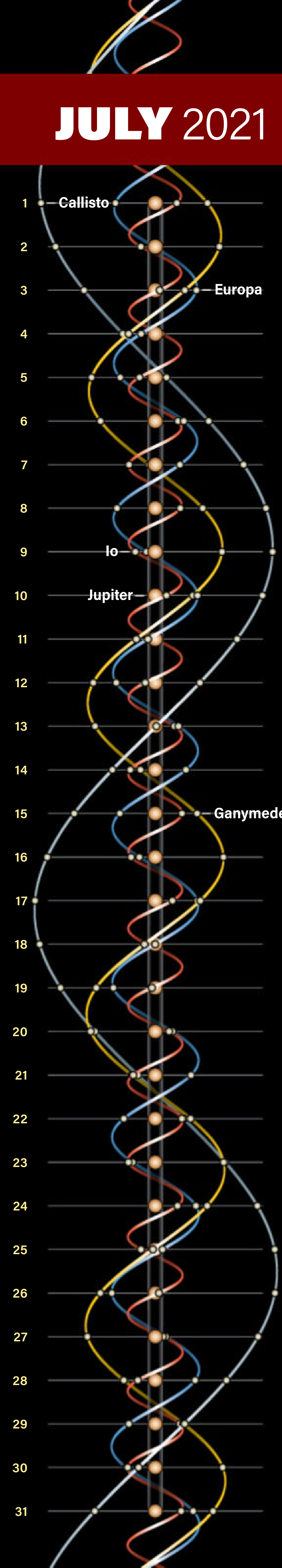
JULY 2021



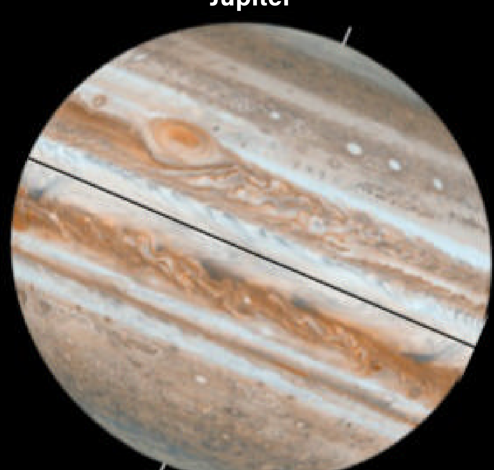
Early evening

JUPITER'S MOONS

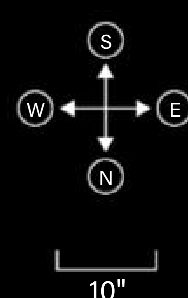
Dots display positions of Galilean satellites at 4 A.M. EDT on the date shown. South is at the top to match the view through a telescope.



Jupiter

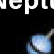


Saturn



Uranus

Neptune

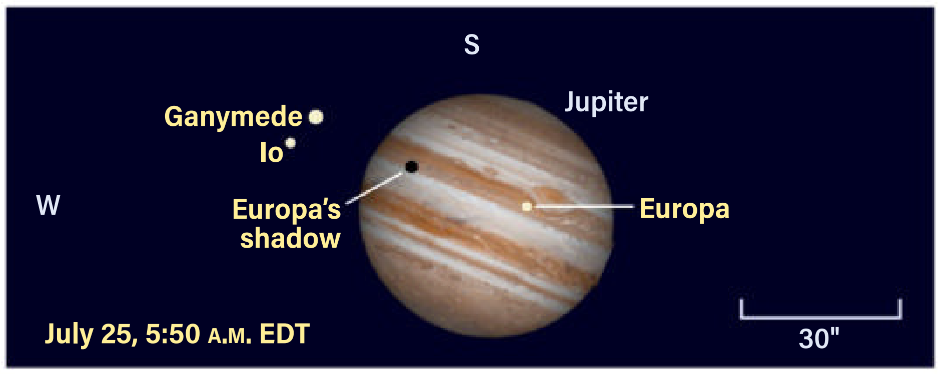


Pluto

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
July 15	July 15	July 15	July 15	July 15	July 15	July 15
1.8	9.2	–2.7	0.2	5.8	7.7	14.9
3.8"	0.4"	46.9"	18.5"	3.5"	2.3"	0.1"
98%	98%	100%	100%	100%	100%	100%
2.494	3.256	4.199	8.986	20.096	29.408	33.306
1.666	2.852	5.035	9.953	19.746	29.924	34.321
9h32.8m	3h35.3m	22h13.5m	20h55.5m	2h46.6m	23h35.4m	19h50.4m
15°48'	12°42'	–12°08'	–18°08'	15°38'	–3°54'	–22°37'

 — Continued from page 33

Triple play



On July 25, three of Jupiter's Galilean moons undergo several events in succession: two transits and an eclipse. Callisto (not shown) is 10' east of Jupiter.

will prove exceedingly challenging, since Saturn will be overexposed in short shots but long exposures are required to capture the galaxy.

Saturn brightens from magnitude 0.3 to 0.1 by the end of July, dominating the constellation Capricornus the Sea Goat. Telescopic views reveal its 18"-diameter disk, encircled by the magnificent ring system spanning 42" along its long axis and 12" along the short axis. Saturn's polar diameter of 17" shows off more of the south polar area than in recent years.

Magnitude 8.5 Titan is an easy target for small scopes. It lies north of Saturn July 2 and 18, and south of the planet July 10 and 26. Three smaller, magnitude 10 moons orbit closer to Saturn: Tethys, Dione, and Rhea change relative positions hourly. Even fainter is magnitude 12 Enceladus, hugging the outer regions of Ring A.

Iapetus reaches western elongation July 4, sitting 9' due west of Saturn near 10th magnitude. By its July 24th superior conjunction, it's dimmed to near 11th magnitude.

We're entering peak **Jupiter** viewing season for 2021. The giant planet rises in the hour before midnight on July 1 and by the end of twilight at the end of the month. This places it near the meridian in the early morning hours — the best time to view it. Jupiter is moving retrograde in Aquarius near its border with Capricornus and lies about 20° east of Saturn.

It's a dominant object in this region of the sky, shining at magnitude –2.7 most of the month and reaching –2.8 by the end of July. Telescopic views will show a wide range of cloud features on its 48"-wide disk. These features move quickly with the planet's rotation period of just under 10 hours. Two dark equatorial belts straddle the equator and carry with them dark and light regions, along with more spots and belts in the temperate regions.

Io, Europa, Ganymede and Callisto — Jupiter's four major moons — wander to different positions each night. You can track them easily with a small telescope and follow the occasional transits of moons and their shadows. Moons also sometimes hide in or reappear from an eclipse behind Jupiter or its shadow, which extends away to the west of the planet before opposition.

A thrilling series of events occurs July 24/25. The shadow of Europa joins the largest moon, Ganymede, in a transit of Jupiter, while a short time later, Io enters an eclipse. Such simultaneous events are rare and fun to watch as orbital dynamics play out right in front of you. Note that some events are not visible from all locations in the U.S., so check the times for sunrise and the altitude of Jupiter at your location.

Neptune sits 12° due west of the Last Quarter Moon early on the morning of July 1. Binoculars are sufficient to detect the magnitude 7.7 planet. Located in eastern Aquarius, Neptune is moving retrograde, heading toward a September opposition. It rises around midnight and is best placed for viewing from 2 A.M. local time

WHEN TO VIEW THE PLANETS

EVENING SKY
Venus (west)
Mars (west)
Jupiter (east)
Saturn (east)

MIDNIGHT
Jupiter (southeast)
Saturn (southeast)
Neptune (east)

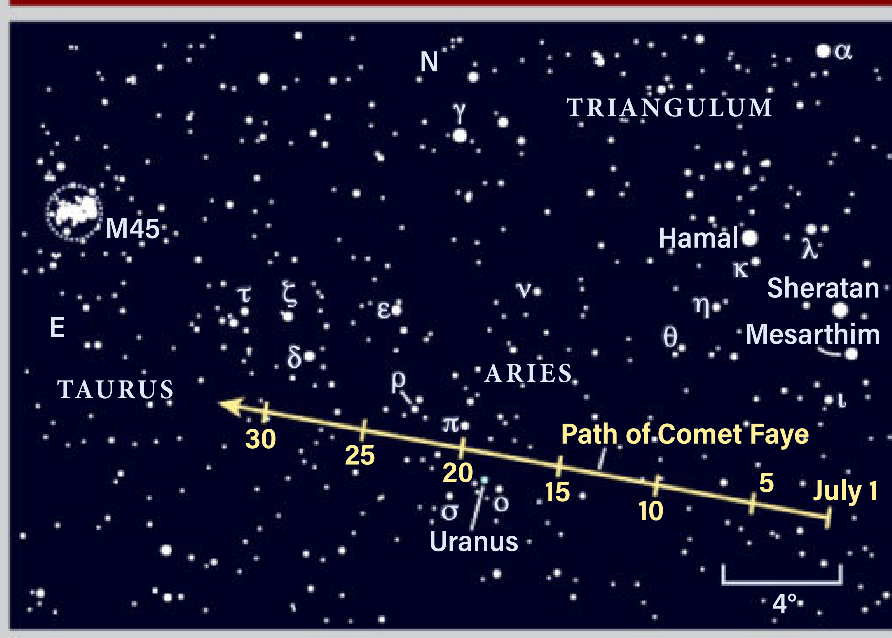
MORNING SKY
Mercury (east)
Jupiter (south)
Saturn (southwest)
Uranus (east)
Neptune (south)

COMET SEARCH | Higher flier

CLEAR SUMMER NIGHTS often leave you wanting more. If your latitude only gives you four hours of darkness, going 'till 3 A.M. is worth the preparation. Several periodic comets float in the predawn sky: 15P/Finlay and 8P/Tuttle are low in the horizon haze, while 4P/Faye glides above.

Dark country skies are needed to pick up Faye's 10th-magnitude glow in a 4-inch scope. An 8-incher should reveal a stubby tail off to the north, while the southern flank sports a more well-defined boundary. Although Faye returns every 7.5 years, we only get a decent look every 15, because that extra six months puts Earth on the far side of the Sun in our January location every other orbit.

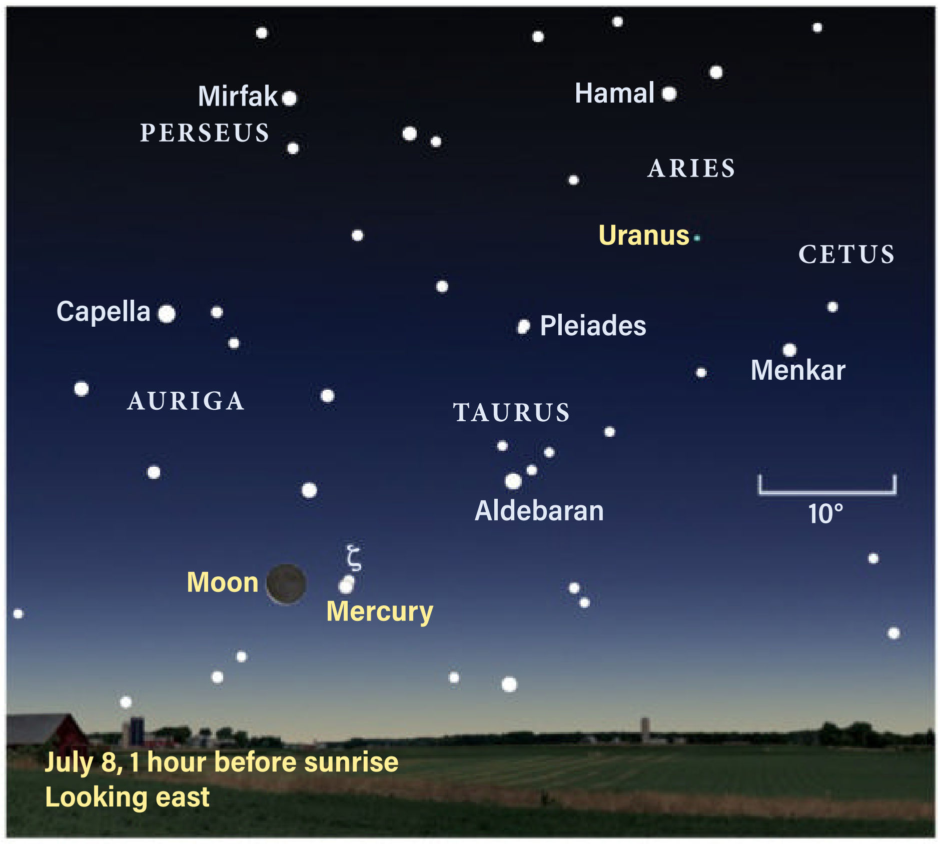
Comet 4P/Faye



Spanning less than 2 miles, Faye relies on its proximity to Earth to glow nicely. It's OK to hope that another surprise like last year's C/2020 F3 (NEOWISE) catches our attention.

Faye never comes inside Mars' orbit, so a slightly closer opposition makes a huge difference in peak magnitude. Just how close is not precisely known. Jupiter's gravitational tugs, added to the jet effects of outgassing, creates uncertainty in the comet's position and perihelion date until we nail it on an image.

Mercury meets the Moon



Mercury appears level with the crescent Moon the morning of July 8. The location of Uranus is also shown — you can find it with binoculars.

through dawn in early July, and from midnight through dawn late in the month. Neptune lurks 5.8° east of Phi (ϕ) Aquarii and due south of the Circlet in Pisces. It lies very near a slightly brighter field star (HIP 116402, magnitude 7.2) and appears like a double star under low magnification. Neptune's motion relative to the field star is noticeable from night to night. The planet lies 4.1' due south of this star on July 18 and continues westward, ending the month 14' to its southwest. A gibbous Moon returns to Aquarius the morning of July 27, when Neptune stands 8° to its northeast.

Uranus is best viewed in the hour before dawn, high in the southeast among the faint stars of southern Aries. Binoculars will easily reach the magnitude 5.8 planet, although its exact location is tricky given the sparse star field. On July 1, Uranus is 12' due north of magnitude 5.8 Omicron (ο) Arietis. Find Omicron by picking up 4th-magnitude Mu (μ) Ceti, the northernmost star in the head of Cetus the Whale, then moving due north past 38 Arietis (2° north of Mu) until you reach Omicron, 3° north of 38 Ari.

During July, Uranus treks northeastward and is nearly 1° from Omicron on July 31. It is then 14' due north of a fainter (magnitude 6.7) field star. Through a telescope, Uranus reveals its planetary nature in the form of a 4"-wide blue-green disk. A waning crescent Moon lies in the vicinity the morning of July 4, when Uranus stands 4.5° to its northeast.

Mercury reaches greatest western elongation (22°) from the Sun on July 4, when it rises 80 minutes before sunrise. Its dim magnitude 0.5 will make it a challenging object low in the eastern sky — use Aldebaran in Taurus as a guide. The star rises half an hour earlier and sits 11.5° due west of the planet.

Mercury's visibility improves even as its elongation shrinks because its brightness increases. Try on July 7, when it glows at magnitude 0.2 and stands 8° below the waning crescent Moon. Try again the next morning (July 8), when Mercury is 0.1 magnitude brighter and the exceedingly thin crescent Moon lies level with it above the horizon. Both rise 85 minutes before the Sun. An hour before sunrise, they stand 3.5° high in the east. Can you spot Zeta (ζ) Tauri 0.5° above Mercury?

Mercury is a lot brighter July 12, standing 3° high an hour before sunrise and magnitude –0.3. A week later (July 19), it has brightened to magnitude –1 but its separation from the Sun is declining. Now you have to look later — 45 minutes before sunrise — to see Mercury 3° high. It sinks quickly over the following week and becomes lost in twilight as it approaches next month's superior conjunction.

Martin Ratcliffe *is a planetarium professional and enjoys observing from Wichita, Kansas.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

LOCATING ASTEROIDS

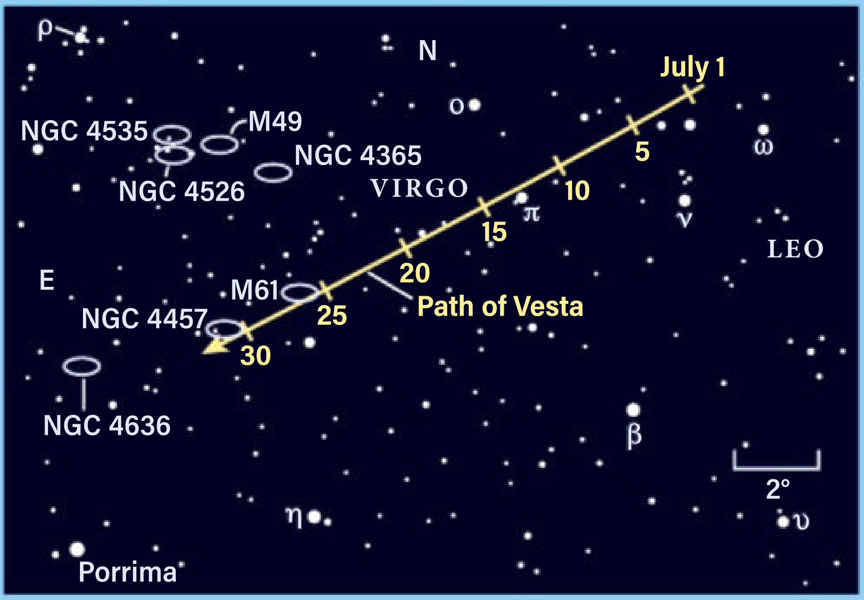
Suburban sighting

AS DARKNESS FALLS, bright blue-white Regulus and Spica twinkle in the southwest. Halfway between them and a few degrees above, magnitude 7.4 asteroid 4 Vesta runs eastward against the stars at ½° per night, slowly dropping behind Earth's 1° per day. Virgo is an ideal place to track it: the constellation sports a scattering of 3rd- to 6th-magnitude landmarks and uncrowded views with only one or two field stars brighter than Vesta.

Still easy from the suburbs in the smallest of scopes, Vesta is becoming challenging in binoculars under the veil of light pollution. With a handful of stars plotted on a logsheet, you can readily see which dot moves night to night. If you pick Pi (π) Virginis as your anchor, for five nights centered on the 13th, Vesta will be less than 1° away. The First Quarter Moon passes by on the 15th without issue.

To see Vesta shift against the background stars in one observing session, the 1st, 13th, and 19th offer great backdrops. Supernova hunters will skip a heartbeat on the 27th, when Vesta slips 20' south of majestic spiral M61. If you're finishing off your Virgo Messiers on Saturday the 31st, drop in on Vesta posing next to bright NGC 4457, just a few degrees southeast of M61.

Gliding among galaxies



Vesta passes several deep-sky objects on its way through Virgo.

Target easy deep-sky objects

With a modest telescope, you can spot these celestial beauties.

BY DAVID FULLER

IN 2010, I STARTED making YouTube videos to help people glimpse interesting celestial objects, from the planets to galaxies and everything in between. All the while, I also tried to educate them about observing equipment and the issue of light pollution. The series, *Eyes on the Sky*, celebrated its 10th anniversary last November.

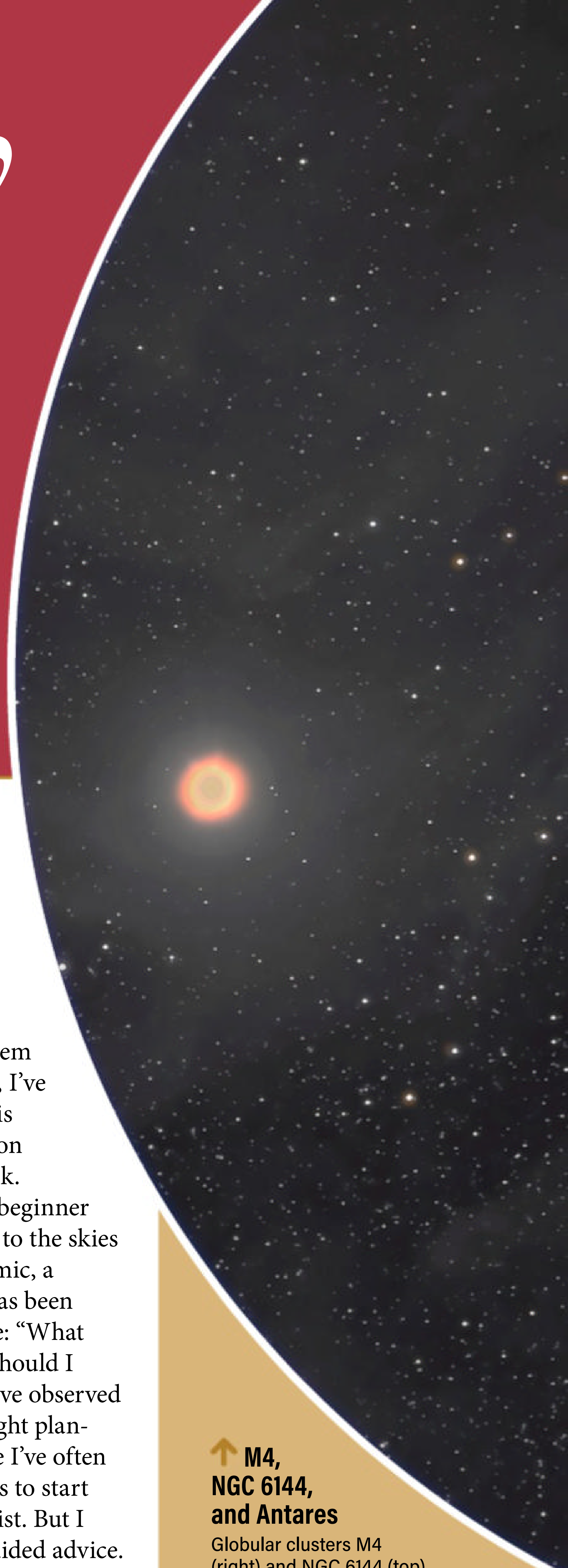
Since the program's inception, I've been fortunate enough to both lead and participate in live outreach events across the greater Chicagoland area, despite its light-polluted skies. My outreach adventures have also taken me to suburban libraries, local forest preserves, community centers, and even to California's redwood forest and Pennsylvania's Allegheny National Forest.

Suffice to say, I've interacted with many amateur and experienced observers, both virtually and in person, during that time. And one popular question that always seems to crop up, no matter the observer's experience or desired target: "How do you know where to find that?"

Once I noticed, I started making a mental list of commonly requested targets, and eventually I started writing them down. Since 2012, I've been tweaking this master list based on in-person feedback.

With so many beginner observers turning to the skies during the pandemic, a related question has been popping up online: "What deep-sky objects should I hunt down after I've observed the Moon and bright planets?" The response I've often seen from others is to start with the Messier list. But I think that's misguided advice.

Stay with me; let's walk through this. A logical beginner might think: "OK, what's the first object on the Messier list? Oh, Messier 1, the Crab Nebula. I've seen photos of that online — it is amazing! I just got a telescope for Christmas and this object is in my sky tonight. So, let's start at the start."

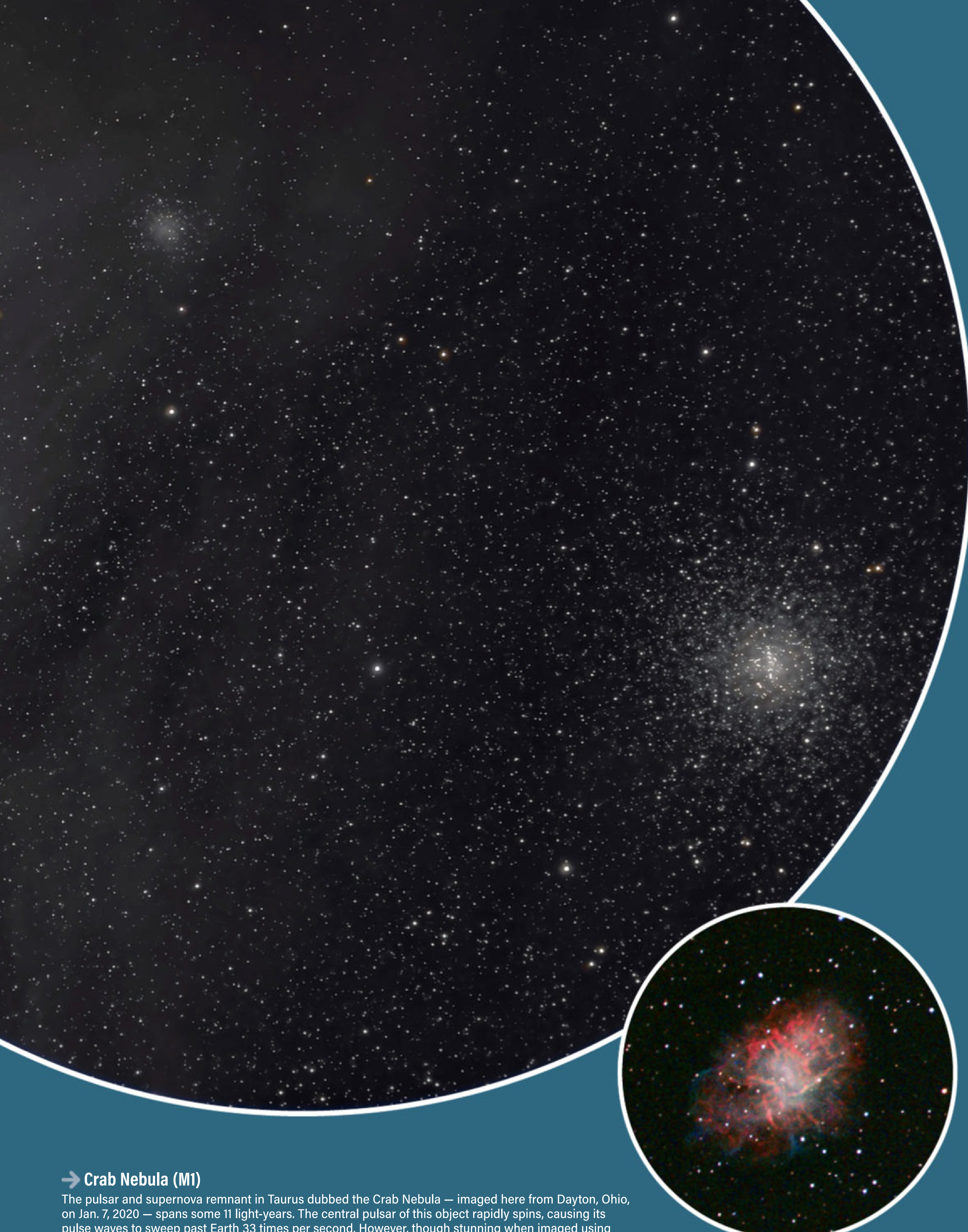


M4, NGC 6144, and Antares

Globular clusters M4 (right) and NGC 6144 (top), along with the bright star Antares (left), were captured here through a 4-inch refractor with a Canon 20Da camera at ISO 800 (four stacked five-minute exposures). The image was taken from Coonabarabran, New South Wales, Australia, on March 27, 2007. ALAN DYER

Dumbbell Nebula (M27)

The Dumbbell Nebula is seen here through a 5-inch refractor, captured with a Canon 7D camera at ISO 800 (six stacked five-minute exposures). ALAN DYER



Crab Nebula (M1)

The pulsar and supernova remnant in Taurus dubbed the Crab Nebula — imaged here from Dayton, Ohio, on Jan. 7, 2020 — spans some 11 light-years. The central pulsar of this object rapidly spins, causing its pulse waves to sweep past Earth 33 times per second. However, though stunning when imaged using advanced equipment, beginning observers with modest scopes will likely be disappointed. JOHN CHUMACK

Andromeda Galaxy (M31) with strong light pollution
Dark skies make all the difference. In the sketch above, drawn based on what the artist saw through his telescope's eyepiece near the city of Almere in the Netherlands on Oct. 15, 2016, the Full Moon's bright light washed out all but the core of the expansive Andromeda Galaxy. BOTH ILLUSTRATIONS: MARTIJN STRAUB

Andromeda Galaxy with little light pollution
In contrast, this sketch, drawn while observing near the small Netherlands community of Breezanddijk on Nov. 28, 2016, shows much more of the galaxy's width and nebulosity. Its dust lanes, however, remained undetectable.

Now imagine the disappointment of that beginner after observing the Crab Nebula through a 60mm or 70mm refractor under heavily light-polluted skies — assuming they can even find it. I've had trouble viewing M1 with a 76mm reflector using averted vision under decent skies, and I'm a rather experienced observer.

Remember, Charles Messier and his assistant Pierre Méchain did not compile the famed list because they were looking for a bunch of great and bright nebulae for amateurs. Messier was a comet hunter and he kept finding annoying not-comets that he didn't want to distract him from his search. True, he added some questionable entries — M44, M45, and the double star M40 come to mind — but most of the objects on the list could easily be mistaken for comets.

So, should we really expect beginners to be excited about low-surface-brightness objects like M1, M33, M74, M88, or M101? By recommending the entire Messier list, we are indeed recommending many such objects. But I think we can do better. And that's by starting off newbies with targets that are both easily found and clearly visible.

Don't get me wrong; I've included a fair number of brighter Messier objects in my beginner's deep-sky list, which appears later in this article. And those do serve as prime examples for beginners to try observing first, and then continue to check back in on, like revisiting old friends over the years. But even a list of the prime Messiers would leave out many other perfect deep-sky targets for beginners.

When I was a young amateur …

Certainly, back in the day, many of us amateurs learned persistence while tracking down whatever we could find with the telescopes available to us. And, driven by a love of the cosmos and lots of reading, I developed a good sense of what deep-sky objects to seek out. Additionally, I was in an astronomy club where more experienced members were ready and willing to mentor me. The sky was also darker then, so fainter deep-sky sights were easier to locate and view.

Today, you can find a slew of suggestions with a quick search on the internet. But like Forrest Gump's box of chocolates, you never know what you're going to get. Typically, it's an off-the-cuff list of both good (high surface brightness, visually impressive) and terrible (low surface brightness, dim or invisible) objects supposedly for beginners. But they are often simply the favorites of the amateurs suggesting them.

Complicating matters is the fact that, for many, the night sky is the most light polluted it has ever been. And suggesting beginners track down the entire Messier list with 60mm or 70mm refractors is downright unreasonable. Especially since there are far brighter NGC, IC, and double star targets — such as the Double Cluster, Albireo, IC 4665, Alcor and Mizar, and NGC 457 — that are easier to locate and better to observe than the fainter Messier objects.

Curating my list

Over the course of eight years, I came up with a few criteria to help me sort out my recommendations for deep-sky objects for beginners with small scopes, at least for Northern Hemisphere observers.

Here are the three main criteria I used:

Owl Cluster (NGC 457)

If you don't have the photographic equipment (or the astrophotography skills) to capture celestial sights through your scope, consider sketching them instead. This sketch of the Owl Cluster was done at the eyepiece using black Canson paper, a white charcoal pencil, and a kneaded eraser. The astrosketcher then brought it inside to do minor touch-ups and add a bit of color with colored pencils to better represent his view through the eyepiece.

MICHAEL RECTOR

Pleiades (M45)

The Pleiades, commonly referred to as the Seven Sisters, is a easy-to-find and worthwhile sight for beginners to seek out. This shot was captured Jan. 17, 2009, through a 3-inch Borg astrograph refractor with a Canon 20Da camera at ISO 400 (four stacked 18-minute exposures). By opting for long exposures, the photographer was able to tease out the faint details of the reflection nebulosity around these sister stars.

ALAN DYER

EASY TELESCOPIC TARGETS

These are in order of right ascension, so an observer can start with the first object visible on the east side of the sky and observe objects until they near the western horizon (or go the other way).

TARGET NAME	TYPE OF OBJECT	CONSTELLATION
Andromeda and its satellite (M31 and M32)	Spiral galaxy and dwarf galaxy	Andromeda
Achird (Eta [η] Cassiopeiae)	Double star	Cassiopeia
Owl Cluster (NGC 457)	Open cluster	Cassiopeia
NGC 663	Open cluster	Cassiopeia
Double Cluster (NGC 869 and NGC 884)	Open cluster	Perseus
Almach (Gamma [γ] Andromedae)	Double star	Andromeda
M34	Open cluster	Perseus
The Pleiades (M45)	Open cluster	Taurus
Pinwheel Cluster (M36)	Open cluster	Auriga
M37	Open cluster	Auriga
Starfish Cluster (M38)	Open cluster	Auriga
Mintaka (Delta [δ] Orionis)	Double star	Orion
Orion Nebula (M42 and M43)	Nebulae	Orion
"37" Cluster (NGC 2169)	Open cluster	Orion
M41	Open cluster	Canis Major
NGC 2362	Open cluster	Canis Major
Winter Albireo (145 Canis Majoris)	Double star	Canis Major
Algieba (Gamma Leonis)	Double star	Leo
Cor Caroli (Alpha [α] Canum Venaticorum)	Double star	Canes Venatici

TARGET NAME	TYPE OF OBJECT	CONSTELLATION
Mizar and Alcor	Double star	Ursa Major
Jabbah (Nu [ν] Scorpii)	Multiple star	Scorpius
M4	Globular cluster	Scorpius
Hercules Globular Cluster (M13)	Globular cluster	Hercules
NGC 6281	Open cluster	Scorpius
Butterfly Cluster (M6)	Open cluster	Scorpius
Ptolemy Cluster (M7)	Open cluster	Scorpius
IC 4665	Open cluster	Ophiuchus
Lagoon Nebula (M8) and NGC 6530	Nebula and open cluster	Sagittarius
M28	Globular cluster	Sagittarius
M25	Open cluster	Sagittarius
M22	Globular cluster	Sagittarius
Double Double (Epsilon [ε] Lyrae)	Multiple star	Lyra
Zeta (ζ) Lyrae	Double star	Lyra
Wild Duck Cluster (M11)	Open cluster	Scutum
Ring Nebula (M57)	Planetary nebula	Lyra
Albireo (Beta [β] Cygni)	Double star	Cygnus
Dumbbell Nebula (M27)	Planetary nebula	Vulpecula
M15	Globular cluster	Pegasus
M2	Globular cluster	Aquarius
Herschel's Garnet Star (Mu [μ] Cephei)	Variable star	Cepheus

1) The object must be within 8° — a typical finder scope field of view — of a magnitude 3.5 or brighter star to help beginners easily locate the target.

2) It should overlap as many bright stars as possible when viewed through a red dot (zero magnification) finderscope, as these are increasingly found on new telescopes popular with beginners.

3) It must have a high enough surface brightness to be well received through a small telescope, despite light pollution.

The first criterion is important because, despite the roughly 9,000 potentially naked-eye stars visible from Earth, the vast majority of those are rendered invisible by light pollution. Only around 280 stars are magnitude 3.5 or brighter. By choosing these stars as signposts, the search for beginner-friendly deep-sky objects can start with a naked-eye star visible in moderately to significantly light-polluted skies. This is essential for those using non-magnified finders (point two), which is often overlooked in online lists.

As for the third criterion, my past outreach experiences helped me identify what beginners were impressed with at the eyepiece. That's why my list contains a good number of brilliant open clusters, a few impressive globulars, and some of the brightest nebulae. Galaxies often received the least enthusiasm from beginners, but I've sprinkled in a spiral and dwarf to ensure a bit of everything.

Seeing double

Importantly, there is an entire class of objects that we miss altogether if we only focus on the Messier, NGC, and IC galaxies, clusters, and nebulae: double stars. Such targets are great for amateurs, especially under light-polluted skies.

The problem with more expansive deep-sky objects is that, even if they are very bright, their brightness is spread over a large area, often resulting in relatively low surface brightness. This is not the case for double stars. They are pointlike, so there are no surface brightness issues to deal with — visibility is only a question of visual magnitude. Plus, multi-star systems litter the night sky. With so many colorful and interesting stellar duos and trios (and more) in reach of beginners, a thorough list must also include those.

This compilation includes just 40 objects that are accessible to almost anyone. Such a relatively short list allows a beginner to enjoy multiple quick successes.

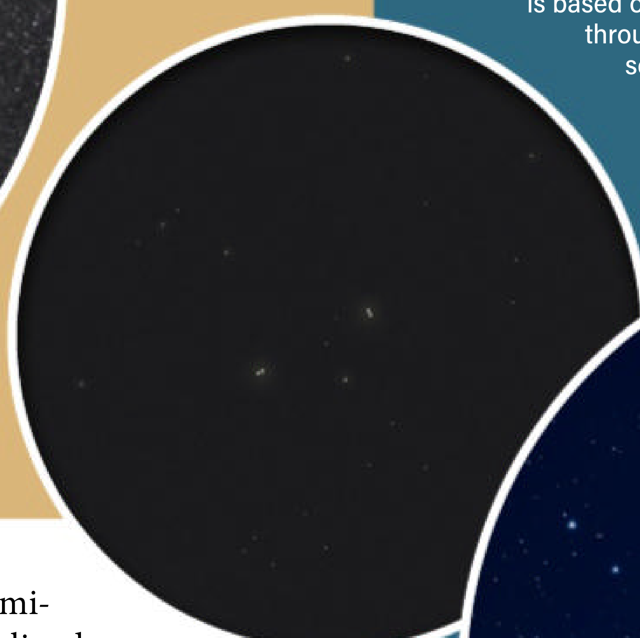
So, start to work your way through my official

"37" Cluster (NGC 2169)

Some 7 light-years across and roughly 3,600 light-years distant, NGC 2169, also known as the "37" Cluster, is a relatively small open cluster in the constellation Orion. It is seen here the night of Jan. 9, 2021, through an 8-inch Schmidt-Cassegrain telescope. MICHAEL RECTOR

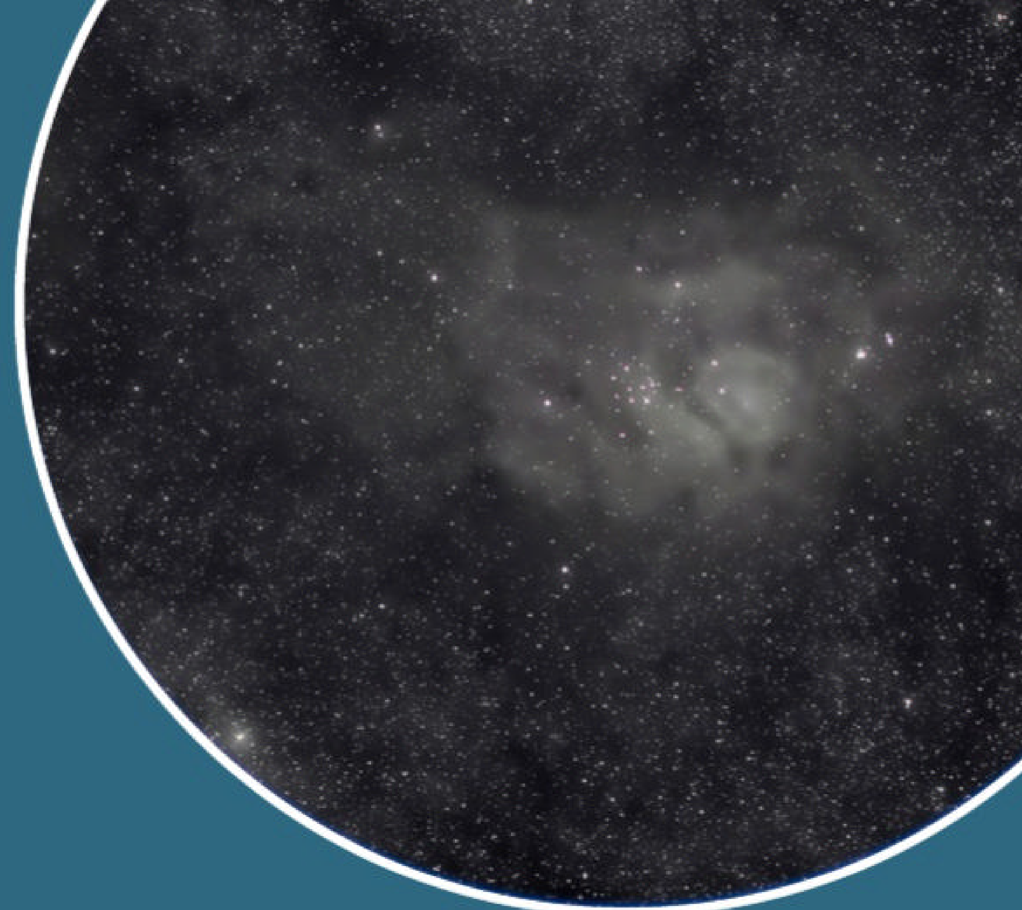
Ptolemy Cluster (M7)

The naked-eye stars of the Ptolemy Cluster pop in this image taken through a 4-inch refractor using a Canon 20Da at ISO 800 (two stacked four-minute exposures) from Queensland, Australia, on July 30, 2006. ALAN DYER



Double Double (Epsilon Lyrae)

Located near the bright star Vega, the multiple-star system Epsilon Lyrae is easy to find. This sketch is based on the view through a 10-inch scope. MARTIJN STROUB



Lagoon Nebula (M8)

With his 4-inch refractor pointed nearly straight up, the photographer captured this view of the Lagoon Nebula using a modified Canon 5D camera at ISO 400 (four stacked 16-minute exposures) from Coonabarabran, New South Wales, Australia, on April 24, 2007. ALAN DYER

Orion Nebula (M42 and M43)

Despite the First Quarter Moon illuminating the background sky, this stunning view captures the Orion Nebula — with larger M43 at center and smaller M42 sitting just to its upper left — as well as the so-called Running Man Nebula (NGC 1975), which is visible near the top. The colorful shot was created by blending multiple sets of long exposures captured through a 4-inch refractor using an unmodified Nikon D750 at ISO 200. ALAN DYER

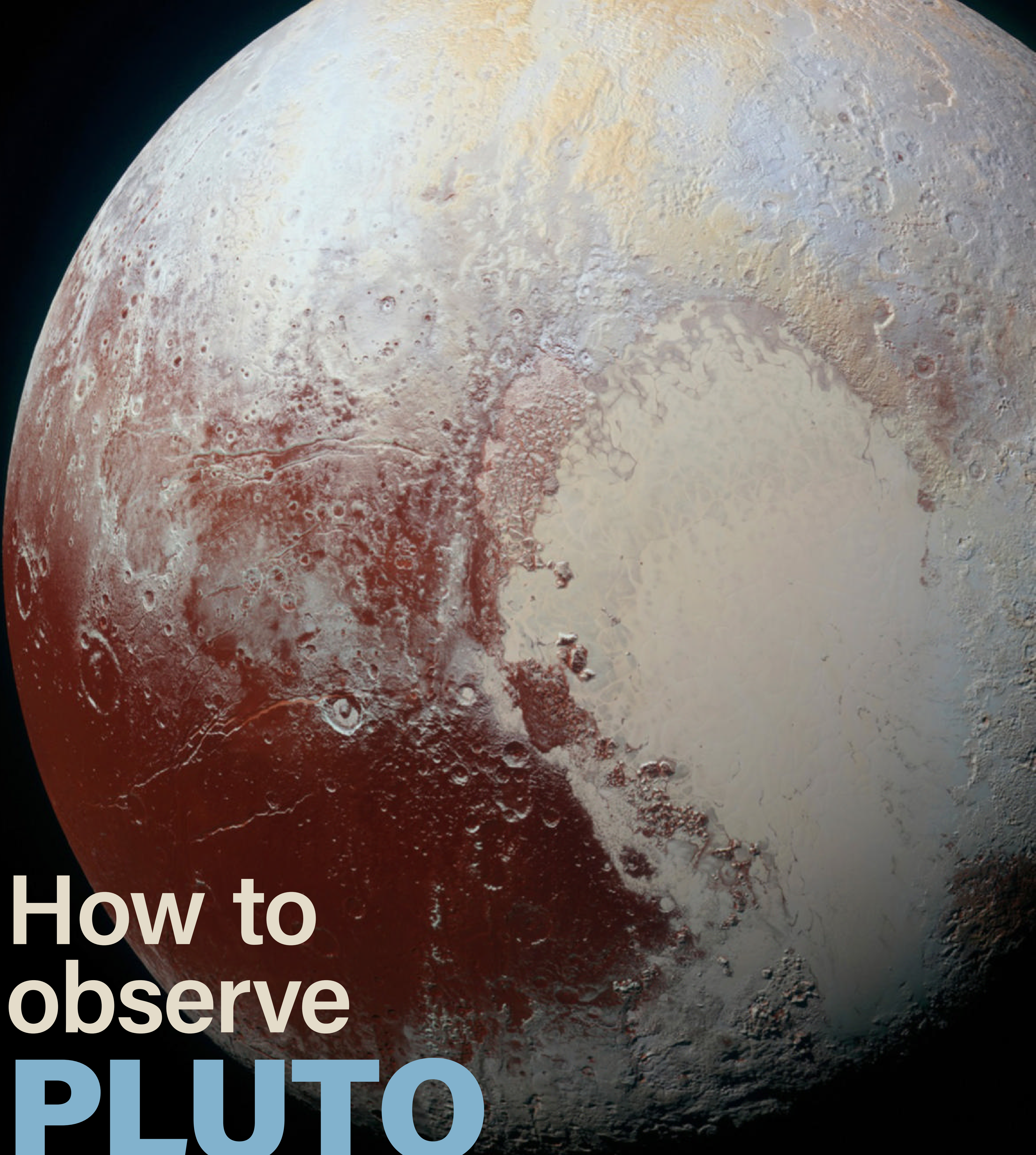
"Telescopes on the Sky" list, which includes 17 open clusters, 11 double or multiple stars, six globular clusters, four nebulae, two galaxies, and a lone variable star. You can also access the list at http://eyesonthesky.com/tutorials/telescopes-on-the-sky, where you'll find further details on locating and observing each target.

Easy telescopic targets

I hope you feel the urge to share this new beginner's list of deep-sky objects with your astronomically inclined friends. And, if you're interested, consider joining me in advocating for darker nights. That won't just help us all get a better night's sleep, it will also help unlock views of the many beautiful distant objects that circle above our heads every night — most of which few beginners have had a chance to glimpse.

Keep your eyes on the sky and your outdoor lights aimed down. That way, we can all see what's up!

David Fuller *is a longtime amateur astronomer who created the popular YouTube series* Eyes on the Sky. *He is also a strong advocate for darker nights.*



How to observe PLUTO

The dwarf planet reaches opposition July 17. Here's what you need to know to spot it.

BY MICHAEL E. BAKICH

Created by combining images taken by the New Horizons spacecraft as it zipped by Pluto in 2015, this enhanced-color view reveals the complex geography of the dwarf planet. NASA/JHUAPL/SWRI

ON JULY 14, 2015, the New Horizons probe swept within 7,700 miles (12,400 kilometers) of Pluto's surface. With the flyby, features that the Hubble Space Telescope previously saw as fuzzy spots suddenly resolved into broad canyons, flowing ice, expansive craters, mountains of frozen water, and a giant glacier only 10 million years old. The spacecraft proved that Pluto is still a geologically active world, but it also provided a list of questions that will take scientists decades to answer.

Still, researchers aren't the only ones entranced by the wondrous world of Pluto — amateur astronomers across the globe are eager to check the dwarf planet off their observing bucket lists. Luckily, this summer, Pluto moves into prime position. Well, about as prime as it gets for the distant dwarf planet.

Prepare for the hunt

Because Pluto glows dimly at magnitude 14.3 and appears as a mere point of light through any telescope, simply identifying it brings a sense of satisfaction. But to see it, you need the right telescope, a dark site, and the star charts that accompany this story.

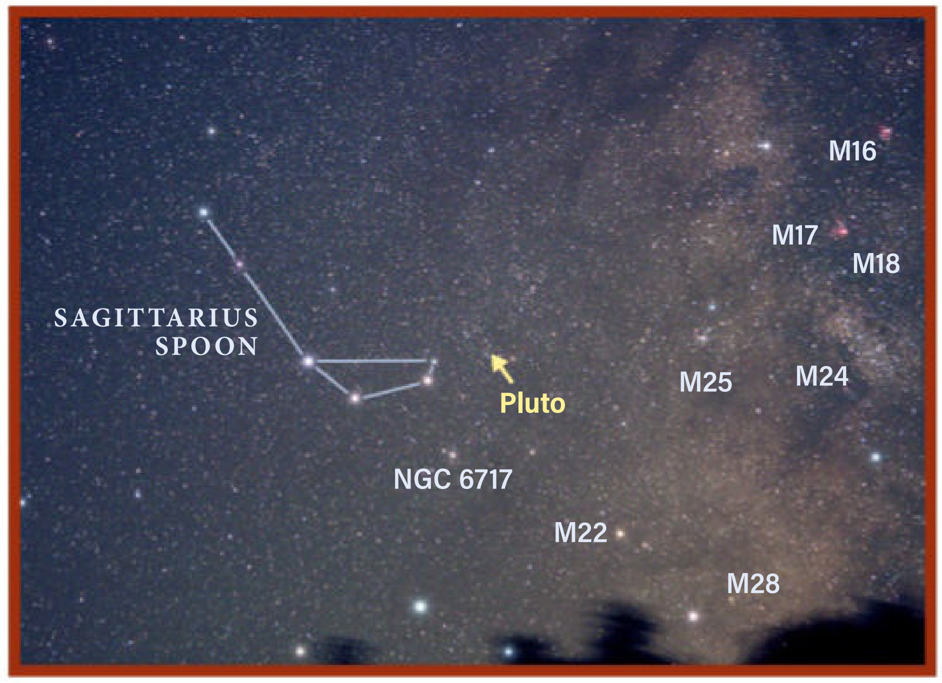
The frozen world reaches opposition July 17. At that point, it lies opposite the Sun in our sky and is visible all night. Pluto's visibility changes so slowly, however, that it remains just as easy to spot for a few weeks on either side of this peak date. That's good, because the 17th is the date of the First Quarter Moon, which will scatter enough light throughout Earth's atmosphere that it will make finding Pluto difficult. Better to try to find it within a few days of July 9, the date of New Moon. On that date, Pluto will be only 0.008 magnitude fainter than it will be at opposition — in other words: no difference.

An 8-inch telescope will be enough to reveal Pluto, although a larger instrument, which collects more light, will make the task quite a bit easier. Once you've got your gear lined up, locate an observing site that isn't simply dark, but also has good seeing, or atmospheric steadiness.

Track down Pluto

On July 9, the dwarf planet lies in eastern Sagittarius, 3.5° west of the globular cluster M75. Its right ascension is 19h51m, and its declination is –22°35'. Pluto takes about 248 years to orbit the Sun once, and it has been strolling through this constellation since December 2009. It won't enter the neighboring one, Capricornus, until early 2024.

Use the charts on pages 48 and 49 to help you to pick out the world from the background stars. But make sure to use a dim red light to illuminate these charts. That color has the least



Pluto is seen here crossing the rich star fields of the constellation Sagittarius the Archer on June 29, 2014. The photographer captured this four-minute tracked exposure at around 3:50 A.M. CDT from Dexter, Iowa. JOHN CHUMACK

ASTRONOMY MAGAZINE'S PLUTO GLOBE

As soon as the New Horizons spacecraft began to send data — especially photographs — back to Earth, former *Astronomy* Senior Editor Michael E. Bakich started thinking about creating the very first globe of the distant world. He knew it would be popular with our readers.

Bakich initially contacted New Horizons Principal Investigator S. Alan Stern, who directed him to Ross A. Beyer, an affiliate of New Horizons' Geophysics Imaging Team.

Beyer collected and organized the data and circulated drafts of the maps among his team for comments and approval. He also worked with *Astronomy* Art Director LuAnn Williams Belter to make sure the features were displayed correctly, the hemispheres lined up, and the color was correct.

If you'd like to adorn your home with a 12-inch globe of this most distant world, head online to **www.MyScienceShop.com**.

impact on dark adaptation of your eyes, though even red light will ruin your night vision if it's too bright.

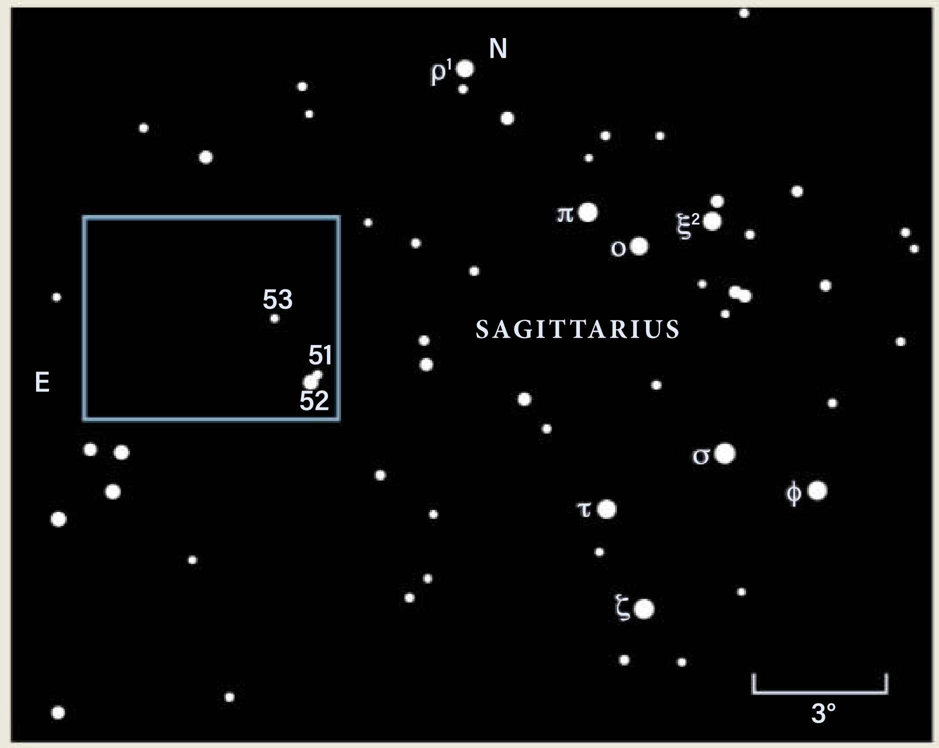
Start with the naked-eye view at the top of this page and identify the handle of the main asterism in Sagittarius: the Teapot. Starting with magnitude 3.3 Tau (τ) Sagittarii — the star that marks the lower left corner of the Teapot's handle — move 7° northeast and find a pair of stars about ¼° apart. They are 51 and 52 Sagittarii (Sgr), which glow at magnitudes 5.6 and 4.7, respectively. An easy way to gauge a 7° angular distance is to use 7x50 binoculars, whose field of view is 7° wide.

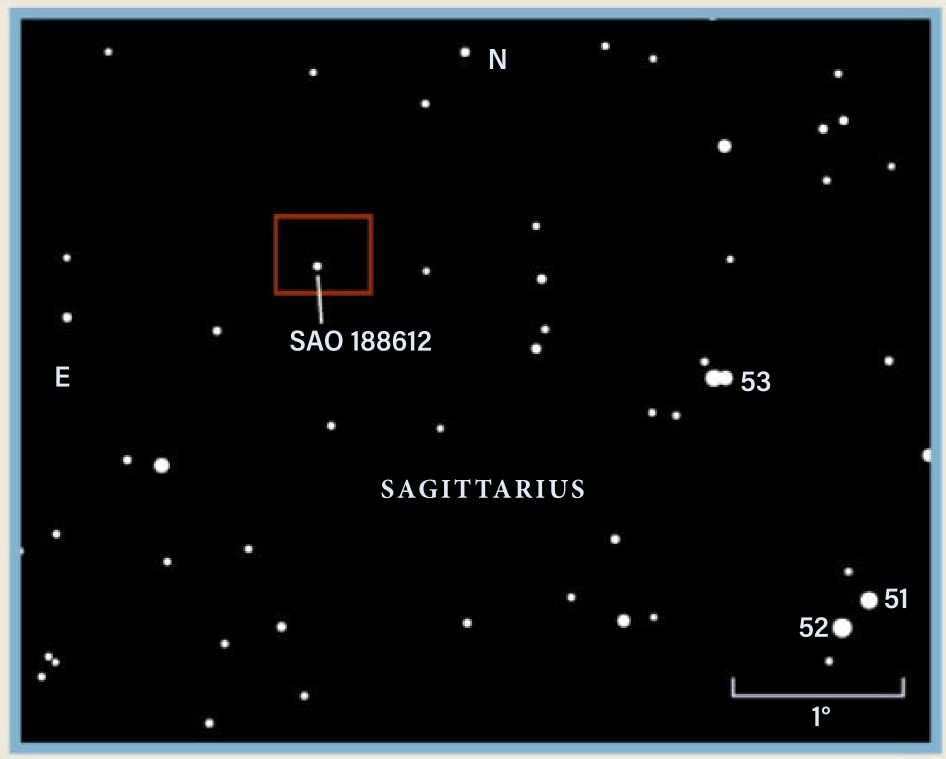
From 52 Sgr, move 1.7° north-northeast to 6th-magnitude 53 Sgr, a close double star. Target 53 Sgr in your binoculars (see the bottom map on this page), then head east and a bit north almost 2.5° to SAO 188612. This star glows at magnitude 7.8 and is the brightest in the area. Center it in your telescope at 11 P.M. EST.

The next brightest star in the region, SAO 188622 (see the telescopic chart on page 49), glows at magnitude 9.9 and is 11' northeast of SAO 188612. Still with me? Hang in there, we've almost arrived. From SAO 188622, a slightly curved line of stars meanders northward. First is magnitude 15.0 GSC 6891:216. If you can see this star, you'll definitely make it to Pluto. Next, head north to magnitude 12.4 GSC 6891:53, then a little farther north to magnitude 13.5 GSC 6891:440. Finally, Pluto's path takes the world just 64" to the northeast of GSC 6891:440.

Over the next few hours, Pluto will trek slightly westward. Outer planets generally move to the east through the stars. But around opposition, Earth overtakes Pluto, causing the dwarf planet to appear to travel westward. This apparent reversal is called retrograde motion. So, if you check the positions of the objects in your field of view every hour or two, one will change its position slightly in relation to GSC 6891:440. That's your target.

The telescopic chart shows all background stars down to magnitude 15, so you should be able to locate Pluto, which glows slightly brighter than this limit. If you can't tell which point of light it is, sketch the stars in the field of view you think is centered on the dwarf planet. Then, at least three nights later, revisit this field and create a second sketch. If you notice that one of the "stars" has moved, you've found Pluto.

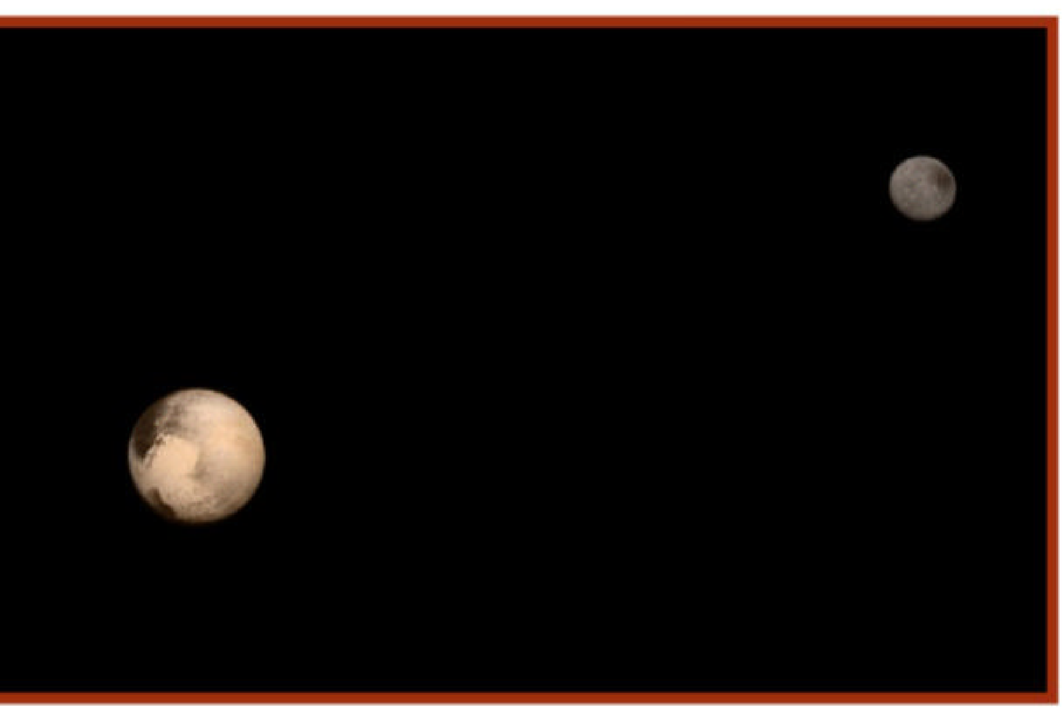




TOP: Eastern Sagittarius stars down to magnitude 6.2 are shown in this naked-eye view. Pluto spends July roughly 10° northeast of Tau (τ) Sagittarii, the lower left corner of the handle of the Teapot asterism.
ALL MAPS: *ASTRONOMY*: ROEN KELLY

BOTTOM: This binocular view shows stars down to magnitude 8.7. Use it to pinpoint magnitude 7.8 SAO 188612, located 2.5° east-northeast of 6th-magnitude 53 Sagittarii.

RIGHT: Pluto moves slowly westward this month, passing 64" northeast of the magnitude 13.5 star GSC 6891:440 on the night of July 9/10. This telescope view shows stars to magnitude 15.0.

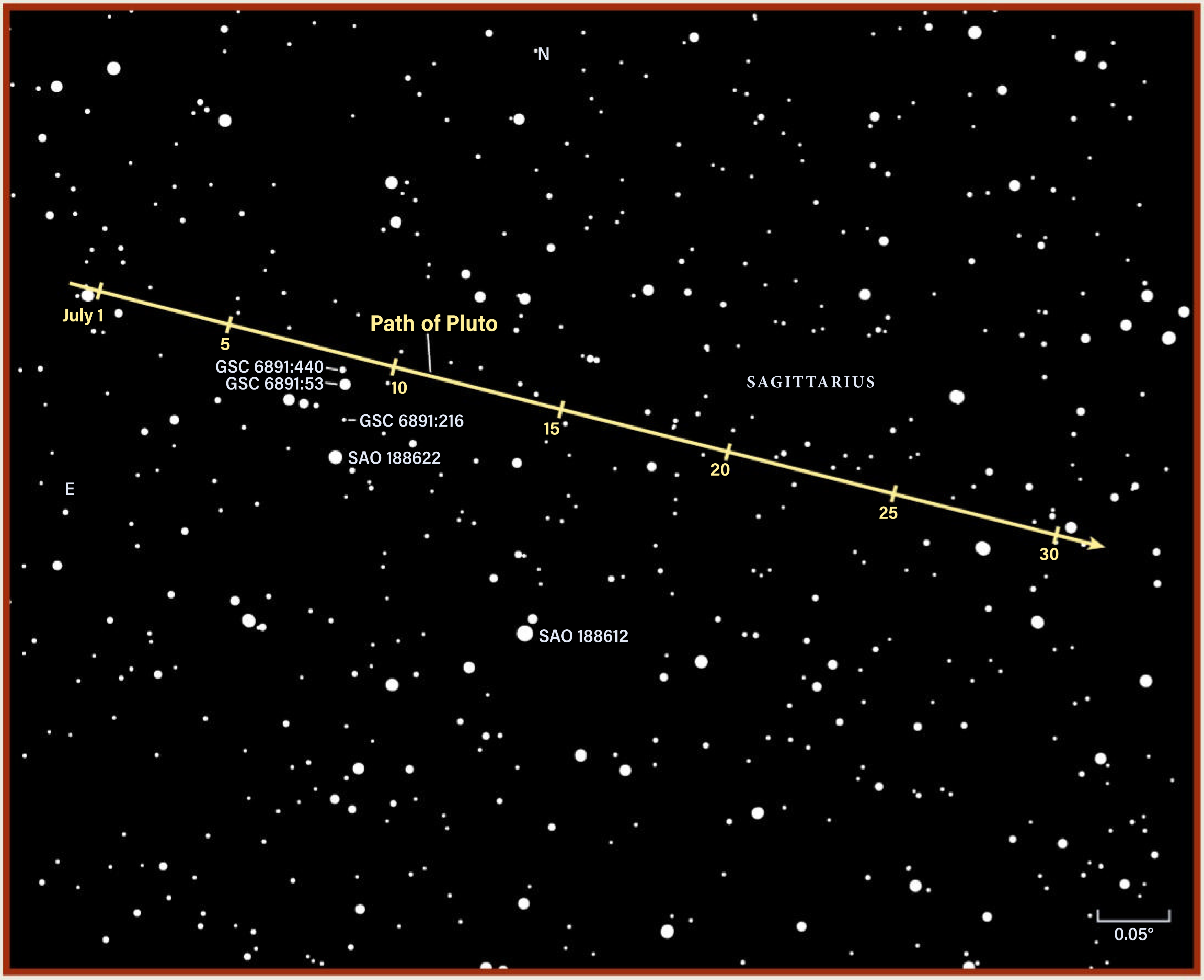


Prior to New Horizons' flyby of Pluto in 2015, the best images of the dwarf planet (left) and its moon Charon (right) were taken by the Hubble Space Telescope — and they resolved little more than blurry bright and dark patches. Fortunately, New Horizons brought these features into crisp view. NASA/JHUAPL/SWRI

Try spotting Charon

Full disclosure: To search for Pluto's largest moon, Charon, you will need a 20-inch scope. First, Charon is two magnitudes fainter than Pluto. And second, the separation between the two bodies is never more than 0.8".

Charon orbits Pluto once every 6.3872 days. Use the orbital diagram at the bottom of page 49 to figure out where the moon lies relative to the planet on any July night. The included table lists the times of the moon's greatest northern elongations. The current geometry of the system places the satellite farthest from Pluto when it sits either north or south of the dwarf planet, though its orbit appears nearly circular from our vantage point.

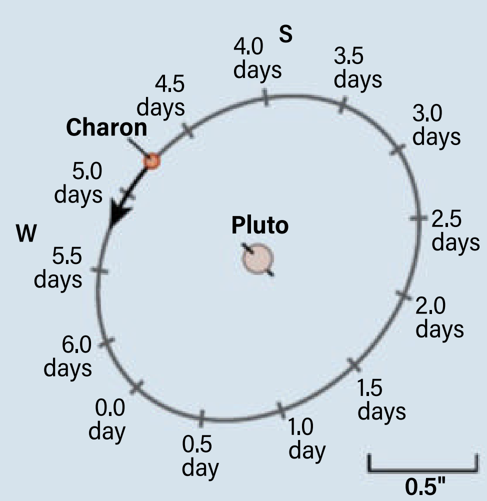


To hunt for Charon, calculate how much time has elapsed since its previous greatest elongation. So, let's say you want to try to observe the moon at 11 P.M. EDT on July 9. The table shows that Charon's previous northern elongation occurred July 7 at 8:54 A.M. EDT, so two days and 14 hours have passed since greatest elongation.

Then, consult the orbital diagram to figure out Charon's approximate location along its orbit about 2.6 days after greatest northern elongation. If you see a faint speck there, you've found Charon. But to be sure, watch it for several hours to see if it keeps pace with Pluto as the system moves past GSC 6891:440. The farther from Pluto the moon appears, the easier it is to spot. The illustration shows south at the top to match the view through most telescopes when Pluto lies highest in the sky.

Relatively few amateur astronomers have ever seen Pluto. So, even though the process is a bit difficult, you'll feel a sense of accomplishment having done it. And as to the question of whether Pluto is a planet, decide for yourself when you catch it in your scope. Good luck!

OBSERVE CHARON



DATE	GREATEST NORTHERN ELONGATION
June 30	11:36 P.M. EDT
July 7	8:54 A.M. EDT
July 13	6:18 P.M. EDT
July 20	4:42 A.M. EDT
July 26	1:06 P.M. EDT

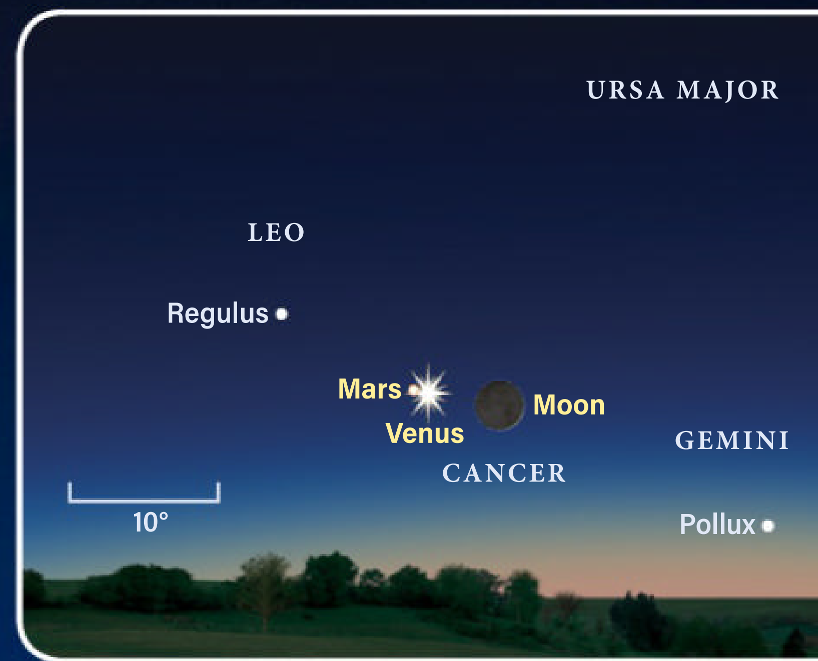
Track down Pluto's largest satellite, Charon, this month by calculating how far the moon has progressed along its orbit since its previous greatest northern elongation. *ASTRONOMY*: ROEN KELLY

Michael E. Bakich *is a contributing editor of* Astronomy *and co-author of* Atlas of Solar Eclipses: 2020-2045 *with Michael Zeiler.*

Venus and Mars meet up

In a public display of conjunction, see Venus and Mars at their finest.

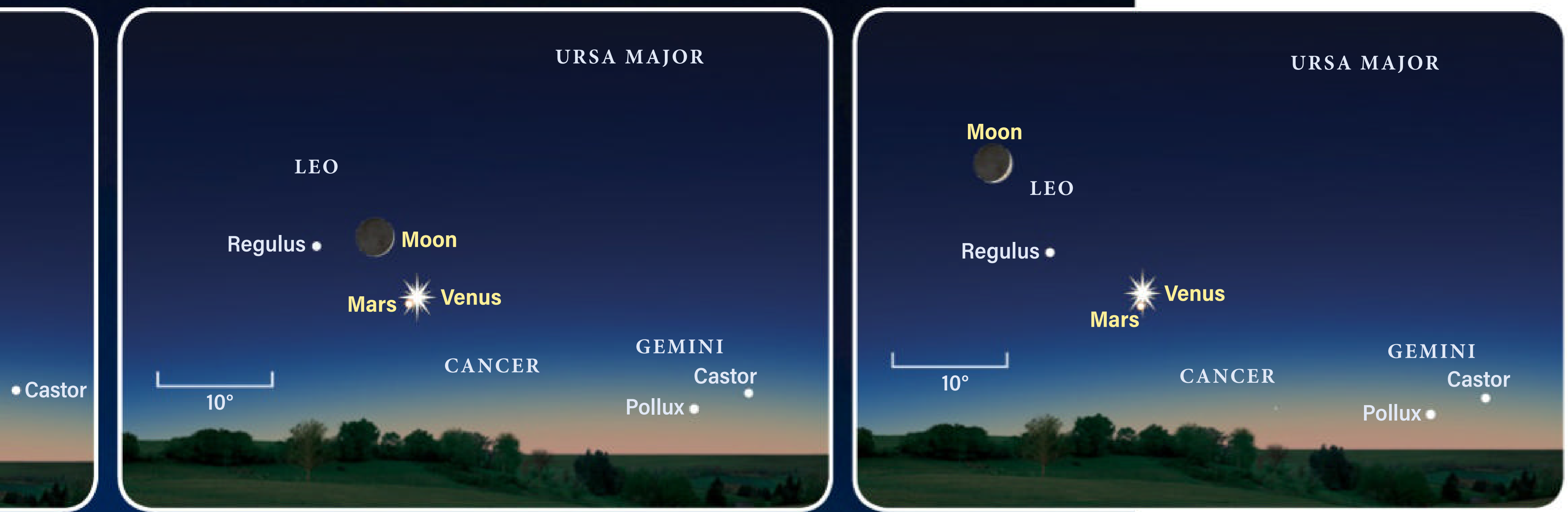
BY MICHAEL E. BAKICH



IT'S A GOOD MONTH for planets. Not only is Pluto reaching opposition July 17 (see "How to observe Pluto" on page 46), but on the 13th, Venus and Mars will appear close to one another in the sky — separated by less than the diameter of a Full Moon. Generally speaking, such an event is called a conjunction (though that term actually refers to when two objects share the same right ascension). This meet-up of Earth's nearest planetary neighbors officially occurs around 2 A.M. EDT. Their closest approach, however, happens some six hours later. That's when the separation between Venus and Mars will be a mere 28.1'.

The Moon's thin crescent will hover near the planetary pair the two previous evenings, offering beautiful views to photographers with clear western skies. On the evening of the 11th, Venus will lie 5.5° southeast of the ultra-thin crescent Moon (5 percent illuminated), which will set about 90 minutes after the Sun. The planets themselves will appear just 1° apart, a distance that is nearly cut in half the following evening. On the 12th, Venus will stand just over 7° west of the 10-percent-illuminated Moon, which sets roughly two and a quarter hours after the Sun. Though the actual moment of closest approach occurs when the pair isn't visible from the U.S., the evenings of both the 12th

This celestial lineup over the Badlands in South Dakota on Sept. 18, 2017, features, from top to bottom: Venus, the magnitude 1.3 star Regulus, the Moon, Mars, and Mercury. GREGG ALLISS



As Venus and Mars approach each other on the night of July 11 (left), a crescent Moon will hover around the pair, about 4 degrees away. July 12 (center) and July 13 (right) afford views of the nearest separation of Venus and Mars, as the Moon buzzes by the two planets and passes into Leo. *ASTRONOMY*: ROEN KELLY

and 13th offer essentially the same separation — about 33'.

Where to look

On July 13th, the pair will become visible about 45 minutes after sunset, local time, low in the west. The two planets will initially stand 16° above the western horizon and then sink below it 1 hour and 42 minutes after the Sun.

You'll probably spot Venus quite a bit earlier, too. It will be its usual brilliant self, shining at magnitude –3.9. Mars, unfortunately, will be quite a bit fainter, glowing at magnitude 1.8. That means Venus will be 190 times brighter than Mars, so you'll have to let twilight fade some for you to be able to spot the Red Planet. Both objects will lie in the constellation Leo the Lion.

When closest, the two objects will be visible through any telescope/eyepiece combination that has a field of view of 0.5° or more. Of course, you also can see them through binoculars or with your naked eyes once the Sun is far enough below the horizon.

Past and future

The last conjunction between Venus and Mars occurred Aug. 24, 2019, when the separation between them was a bit closer: 24'. For that one, however, the planets were only 3° from the Sun, and, therefore, invisible.

The most recent visible pairing happened Oct. 5, 2017. The two planets were just 21' apart and were 23° west of the Sun in the morning sky.

The next Venus-Mars conjunction will occur Feb. 22, 2024. On that date, 38' will separate the pair, which will lie in Capricornus in the morning sky, 26° west of the Sun. In order to see a pairing between Venus and Mars as close as the one this month, you'll have to wait until May 11, 2034.

An easy catch

Close pairings of naked-eye planets aren't rare, but occurrences this easy to see don't happen all that often. And while the event on July 13 won't feature the closest such pairing of objects, it will be easy for anyone with a clear sky to spot, mainly because Venus is involved. Even better, it takes place in the evening. Take this opportunity to be an ambassador for easy observing as you point out the two worlds to your family and friends.

A young Moon plays host to this close encounter between Venus (the bright object at lower right) and Mars (to the upper right of Venus) on Feb. 21, 2015. The 20-second exposure captured the trails of clouds passing across the Moon, as well as earthshine from the part of the Moon unlit by the Sun. JAMIE COOPER

Michael E. Bakich *is a contributing editor of* Astronomy *who will be viewing the conjunction from his home in Tucson, Arizona.*

The magic behind telescope MIRRORS

The optics are what makes a telescope tick, but creating the perfect mirror is an intricate, artisanal process. BY PHIL HARRINGTON

IF YOU HAVE EVER ATTENDED a club star party or an amateur astronomy convention, you have undoubtedly strolled through an observing field. Scattered throughout are silhouettes of telescopes and attendees, all talking shop. Some telescopes are surrounded by small groups, while others are mobbed with people standing in line, waiting for a chance to glimpse the current target.

Often, large-aperture Newtonian reflectors are the most crowded, as their eyepieces reveal details that go unseen in lesser instruments. Whether it's spotting the intricate labyrinths of a bright nebula, the glittering spectacle of a star cluster, or the dim glimmer of a galaxy just this side of infinity, those magnificent telescopes garner more "oohs" and "ahs" per inch of aperture than just about any other.

At the hearts of these outstanding, handcrafted instruments are their optics. The mirrors inside these telescopes are painstakingly and individually crafted by optical artisans. They combine state-of-the-art fabrication techniques with individualized testing to ensure each and every mirror is near perfect.

To find out how they do it, I recently interviewed the owners of several manufacturers of premium optics, including Lightholder Optics, Optiques Fullum, Ostahowski Optics, Waite Research, and Zambuto Optical. Each owner walked me through their thoughts on topics ranging from how they began their careers to the specific techniques they follow to create their masterpieces.

Simple beginnings

These magical mirrors are created in small optical shops by people who typically got into the business by chance.

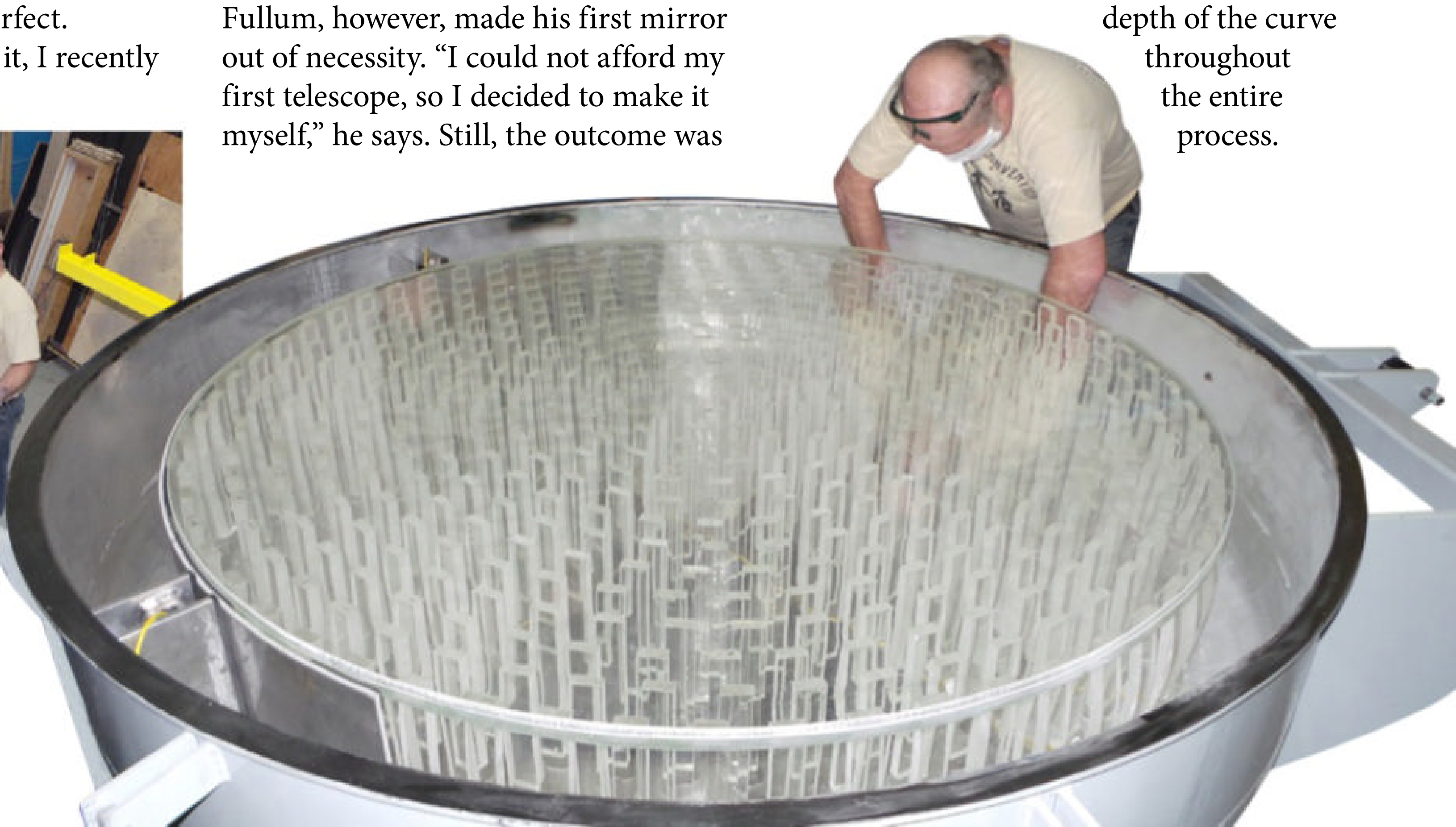
Some had mentors early on who were instrumental to helping them hone their skills. Carl Zambuto of Zambuto Optical credits a local amateur telescope maker, Earl Watts, with convincing him to make his first mirror, a 6-inch. "I had zero interest, but he persisted. So, I [made] the first one and it hit me like a disease," he says. "The following weekend, I was [creating] another one outside on a snowy day at my parents' home in the mountains."

Normand Fullum of Optiques Fullum, however, made his first mirror out of necessity. "I could not afford my first telescope, so I decided to make it myself," he says. Still, the outcome was the same as Zambuto's: "The results were so gratifying that I decided to make a second one and then another one."

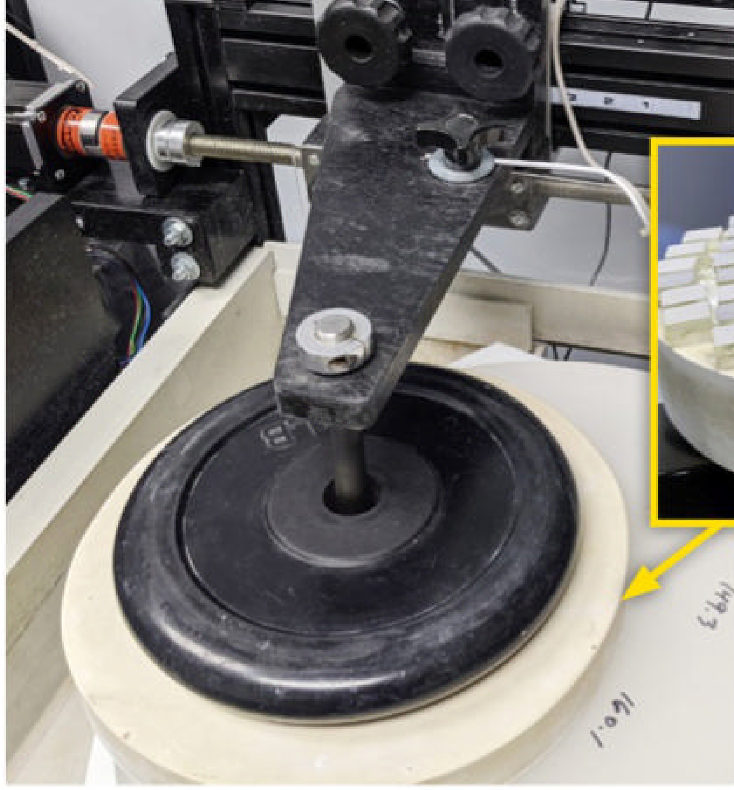
As these amateur telescope makers shared the views through their telescopes with friends and fellow amateurs, fellow hobbyists asked for mirrors of their own. Things started slowly. But as their reputations grew, so did their businesses.

Making a telescope mirror

To start, a new mirror blank is "sanded" down to create a precise parabolic curve in a process called grinding. To do that, the blank is paired with a device called a grinding tool, usually made of glass, plaster, or ceramic. Unlike typical sandpaper strips, the so-called sandpaper used in grinding is actually a mixture of grit and water. A layer of grit is sprinkled on the blank. Then water is sprayed onto the grit and the machine is turned on to spin the grinding tool. More grit and water is added as needed. The coarser the grit, the quicker the grinding — but also the rougher the surface. That's why it's important to frequently measure the depth of the curve throughout the entire process.



At the request of a private owner, Optiques Fullum created this 61.25-inch f/3.5 Techno Fusion mirror. OPTIQUES FULLUM



ABOVE: Grinding tools can be made of a variety of materials, but most common is glass, plaster, or ceramic. WAITE RESEARCH

LEFT: A mirror blank is ready for grinding in this image. A layer of grit and water will be added to the top of the blank before the machine is turned on. WAITE RESEARCH

After grinding comes polishing. At this point, each mirror is tested to check the initial concave curve. A spherical concave curve is usually acceptable for high-focal-ratio mirrors (usually f/10 and above). But the steep angles in lower-focal-ratio mirrors, especially in today's fast sub-f/4 Newtonian systems, require ultrasmooth, precisely crafted parabolic curves to correctly focus incoming light. Therefore, the mirror's surface must first undergo a process called figuring.

Figuring is done by passing a second tool, referred to as a pitch lap, over the mirror by hand while the mirror rotates on the grinding machine. The grit used for this stage of production, technically called polishing compound, allows for very fine adjustments to the curve. This is where the artistry really comes in. Painstaking testing and inspection, followed by slowly correcting hills, valleys, and other irregular zones in the parabolic curve — first with machines and then by hand — are all critical for exceptional results.

To test for any optical imperfections at the final stage, the mirror undergoes several optical assessments using interferometers in controlled environmental conditions. Interferometry testing compares a reference mirror with a known accuracy to the newly manufactured mirror. A laser beam is shot between the two mirrors, creating a series of lines, called fringes, on the surface of the mirror. A computer then reads those lines and averages the results from a series of tests to determine the mirror's accuracy. For manufacturers like Terry Ostahowski of Ostahowski Optics, this computer-generated report is customarily given to the purchaser to objectively prove the mirror's quality.

Once a mirror is fabricated, all that is left is for it to be coated. Some premium mirror makers send their products to reputable coating companies, while others do that step in-house. Regardless, most premium mirrors feature enhanced aluminum coating to reflect 96 percent of the light striking its surface. By comparison, standard aluminizing reflects around 90 percent. The reflective coat is deposited in a vacuum chamber, where the aluminum is evaporated to create a vapor, which evenly coats the mirror. To create an enhanced coating, several layers of dielectric film are added on top of the aluminum. Finally, to prevent scratching, an overcoating of silicon dioxide (SiO_2), which is both hard and transparent, is deposited to protect the delicate surface.

The artistry

While the general process of creating a mirror is the same, each manufacturer has their own quirks and tricks when it comes to producing the finest mirrors.

"Mirror blanks usually start as either molded blanks or glass that is waterjet-cut from flat sheet glass," explains Gordon Waite of Waite Research. "We have developed a computerized, high-speed rough polishing machine programmed with a series of strokes to move the mirror smoothly toward the desired surface shape." This fine-tuning continues up until the final moments of finishing a mirror. For Zambuto, the process is all about control: "This is a two-person shop. We use simple tools and machines that we built." In this way they can control every aspect of mirror manufacturing, from casting the mirror blank to toughening the glass through heating and slow cooling to grinding, polishing, figuring, testing, and coating. Zambuto's machines also offer an added bonus: "Each machine has only one job in the process, allowing us to build the mirrors at lower cost," he says.

Alternatively, you can start the process with a pre-generated blank, saving time and increasing the operations' efficiency. That's the route John Lightholder of Lightholder Optics takes. He then cuts and polishes the mirror's edges in a process called beveling, which ensures the edges of the mirror won't improperly scatter light. "Next," he says, "is grinding with 40-micron aluminum oxide grit" until the mirror is near the desired focal length. Then, he follows up with fine grinding, using "30-, 20-, 9- and 3-micron powders, constantly checking along the way to maintain the desired focal length."

Of those I spoke with, Optiques Fullum has produced the largest mirror: a monstrous 61.25-inch f/3.5 optic. For mirrors larger than 24 inches, Fullum makes his own "Techno-Fusion" blanks that use a unique fusing process, allowing him to build very large, rigid mirrors that are surprisingly lightweight for their size. Rather than solid glass, Techno-Fusion mirrors feature an open central structure consisting of two thin glass disks sandwiching vertical columns of borosilicate glass that support the mirror surface. Not only does this design cut weight, it also shortens the nightly cool-down process needed for image stability.

> The end result is a mirror that is sure to earn "oohs" and "ahs" from anyone who peers through the eyepiece.

No matter the technique, the end result is a mirror that, when placed in a finely crafted telescope, is sure to earn "oohs" and "ahs" from anyone who peers through the eyepiece — especially the proud owner.

Phil Harrington *is a longtime contributor to* Astronomy *and the author of many books.*

Hunting the Little Fox

Join me on my journey through Vulpecula.

ABOVE: Collinder 399, commonly called the Coathanger, is a random grouping of stars in the constellation Vulpecula. JOHN CHUMACK

RIGHT: The Little Fox, tucked between Cygnus to its north and Delphinus and Sagitta to its south, holds plenty of deep-sky beauties visible through even modest telescopes. *ASTRONOMY:* ROEN KELLY

BY GLENN CHAPLE
Glenn has been an avid observer since a friend showed him Saturn through a small backyard scope in 1963.

A clear and moonless July evening is in the offing, and I've decided to turn my attention to the constellation Vulpecula the Little Fox. I'll opt for a quick naked-eye tour of the celestial critter first, then get up close and personal with my binoculars and telescope.

To be properly prepared, I first scout Vulpecula by studying my copy of *Astronomy*'s *Atlas of the Stars*. I also refer to my astronomy guidebooks, consult the internet, and tease through my observing logbooks for sketches and notes on foxy sights I've seen in the past. The finder chart on the next page shows the portion of the atlas I'll be working with. Tonight, the chart will help me navigate my way through the mishmash of faint Vulpecula stars that speckle the summer sky between Cygnus to the north and Delphinus and Sagitta beneath the Little Fox's southern edge.

Sizing up Vulpecula

Vulpecula will challenge my unaided eye. Not one of its stars is brighter than 4th magnitude. And its brightest star, Anser (alpha [α] Vulpeculae) — the only star in Vulpecula that merits a Greek letter designation — shines at a paltry magnitude 4.4. Fortunately, it's just 3° south of 2nd-magnitude Albireo (beta [β] Cygni), so I'll begin my Vulpecula odyssey by dropping down from the Swan to the Fox.

On an average moonless night from my backyard in the suburbs, I can make out naked-eye stars down to about magnitude 5.0. Vulpecula contains only about a dozen stars of that magnitude or brighter. So I'll test my unaided eyesight by seeing how many I can spot, giving me a general idea of the transparency and steadiness of the atmosphere.

Bust out the binos

Next, with 10x50 binoculars in hand, I'll go back to Anser. This red giant of spectral class M0 forms a wide optical pair with the 6th magnitude K0 giant 8 Vulpeculae. Both should glow with a golden-yellow hue, but M-class Anser should appear more reddish due to its lower surface temperature.

Another 5° further along the Albireo-Anser line is the pseudo cluster Collinder 399, also known as Brocchi's Cluster. This target is classified as a pseudo cluster because recent parallax measurements show its component stars lie at different distances from Earth. Brocchi's Cluster may not be a true open cluster, but its brightest stars form a striking asterism called the Coathanger. The atlas shows this degree-and-a-half-long "hanger," which is formed by a row of six stars of magnitudes 5 to 7. Branching out from the center of the hanger is a four-star "hook." I've viewed the Coathanger with binoculars many times in the past, and I'll be back again tonight.

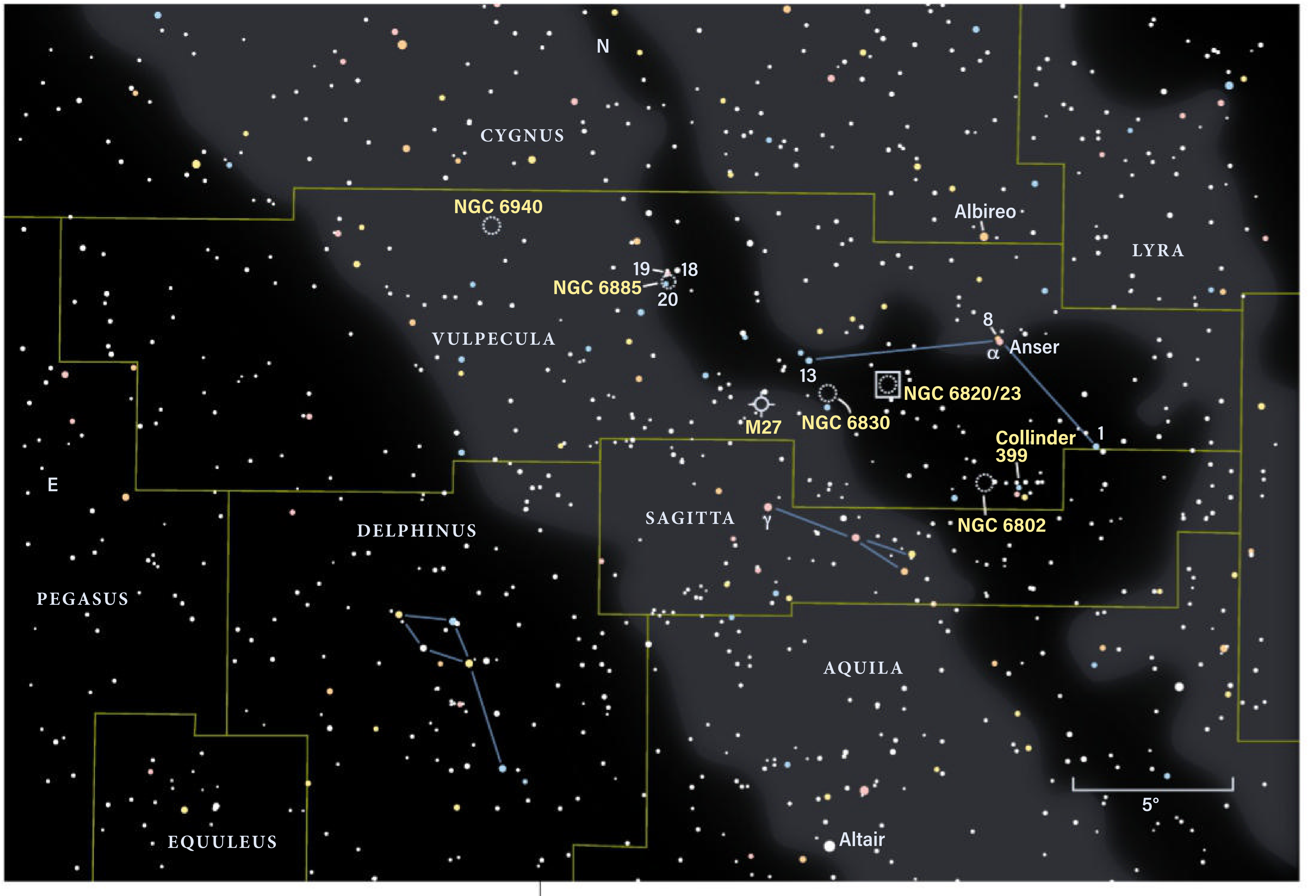
Because much of the western part of Vulpecula is immersed in the Milky Way, it's also home to several honest-to-goodness open clusters. The atlas shows four of them — NGC 6802, NGC 6830, NGC 6885, and NGC 6940 — plus the emission nebula/cluster complex NGC 6820/6823. I've never targeted any of these through binoculars before, but all except NGC 6802 and NGC 6820 should be visible in my 10x50s. NGC 6885 in particular will be a binocular treat. It surrounds the star 20 Vulpeculae and shares the binocular field with 18 and 19 Vulpeculae — a very pretty sight! The Fox's crowning glory is Messier 27, also known as the Dumbbell Nebula. Brighter (magnitude 7.5) and larger (8' by 6') than the typical planetary nebula, the Dumbbell is far and away the most readily visible of them all. I'll find it by centering my binoculars on the star gamma (γ) Sagittae before shifting my gaze 3° northward. That should bring me to the small, misty patch of light.

The Fox's crowning glory is Messier 27, also known as the Dumbbell Nebula.

Call in the big Dob

Moving on to my 10-inch Dob, I'll return to Vulpecula's open clusters. Back in the late 1970s, I viewed NGC 6830, NGC 6940, and NGC 6885 with a 3-inch reflector. They seemed rather faint in that little scope. How much better will they look tonight through the 10-inch?

I've never before seen NGC 6802, which lies at the eastern end of the Coathanger. This cluster is just 5' in diameter, so I'll locate it with low power, then up the



magnification for a better view. The open cluster NGC 6823 is also new to me. At magnitude 7.1 and 12' across, it should be an easy target. If it looks bright in the 10-inch, I might even try viewing it with my 3-inch. And if I'm successful, I'll add it to my lifetime list of deep-sky objects that my plucky little telescope has managed to capture. I'll leave the surrounding nebulosity for the big scope, though, experimenting with various nebula filters if it's not immediately obvious.

Finally, what better way to end my tour of Vulpecula than to turn my 10-inch scope back to the Dumbbell? I've targeted this knotted nebula numerous times over the years, but rarely made in-depth observations with a sizable scope. To do it justice this time, I'll also have a clipboard, log sheet, pencil, and red-filtered flashlight at the ready, allowing me to make a detailed sketch that I can refer back to at any time — no matter the season or weather.

You may not have quite the same tools at your disposal, but I strongly urge you to replicate any or all parts of my journey through the captivating constellation that is the Little Fox. It's worth the hunt.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: Here come the Perseids! Clear skies!

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The Dumbbell Nebula (M27) in Vulpecula is one of the largest and closest planetary nebulae. You'll easily see this magnitude 7.3 object through a small telescope (or even binoculars), but it appears truly spectacular through a large scope. WOLFGANG PROMPER

Odd ducks

It's no surprise when tribe trumps truth.

Why do we still think tribally? It's no longer 100,000 B.C.!
SIRI WANNAPAT/DREAMSTIME

Mad scientists intent on destroying the world make for great comic book villains, but in the real world, there are a lot more Sheldon Coopers than Edward Tellers.

Stereotypes have their downsides, but like pearls around grains of sand, these cliches often grow around a kernel of truth. For the most part, the science set doesn't worry much about its reputation for social awkwardness, but it makes for a fun head scratch. My thoughts on the matter hardly rise to the standards of a theory, but I'll serve them up as a moment's light fare.

Humans are called a social species, but *tribal* is a more accurate word. That part is an honest to goodness falsifiable theory that stands up in the face of mountains of evidence — something as trivial as randomly assigning people caps of different colors can lead to strong enough tribal feelings to bring them to blows.

Humans are called a social species, but *tribal* is a more accurate word.

The key to our evolutionary success was responding to challenges as a single organism with lots of arms, legs, spears, clubs and a willingness to face mortal peril for the good of the whole. We aren't here because our ancestors worried about the niceties of veracity. Blind allegiance to tribe was a key ingredient in a viable gene pool. Fitting in and tribal loyalty are the coin of that realm.

For better or worse, we still carry that evolutionary baggage today. Of course, most people care more about acceptance by their group than they do about silly notions like ethics or whether or not something is true! My tribe, right or wrong. We're here because our ancestors had each other's backs.

Tribalism offered other huge advantages. For one, tribalism reduces the energy we waste by thinking too hard. That 3 pounds of electrochemical circuitry sitting inside your skull is greedy. In a world where calories were hard to come by, the 2 percent of our bodies that our brains make up eats up something like a fifth to a quarter of the energy we take in.

And that share comes off the top: The brain demands the good stuff, blood glucose. Championship chess players can burn over 6,000 calories a day just sitting and staring at the board. The 1984 World Chess Championship was called off without a winner when both contestants were judged physically incapable of continuing play.

By the way, none of this is meant to be at all harsh or pejorative. Honestly. Just like you, I am here because most of my ancestors put tribe first and facts somewhere way down the line. Some of you are doubtless sure that I'm full of it, which is OK. If so, it's probably because this runs counter to the zeitgeist of your tribe, and the last thing your brain wants to do is question that received wisdom.

How's that for meta?

Yet despite all of that whatever-gets-my-genes-into-the-next-generation goodness of tribalism, something like 2 percent of the population is, well, strange. These peculiar folk seem gleeful at the notion that much of what people think is wrong. They even sit around over beer and happily pick each other's ideas to pieces just for fun.

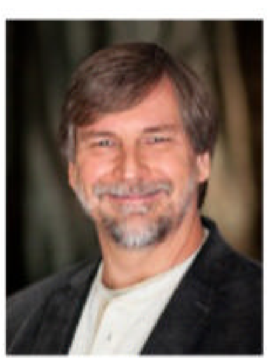
Meet scientists.

So why would a successful tribe tolerate and on occasion even revere such wanton insolence toward cherished norms? The fly in the oh-so-seductive ointment of tribalism is novelty. The world changes, and if the competition keeps coming up with new and better ideas your tribe had better be doing some innovating too.

I'm not saying that some people are born to be scientists. I'm not saying that some aren't. I am saying that scientists' deep and uncommon emotional attachment to truth as an end in itself sets us apart. I am also saying that the tribe needs us, just as we need the tribe. Sometimes it really matters who has the floor.

Not many scientists appreciate how few people care whether their cherished notions are true or not. It befuddles them. Like the child in Hans Christian Andersen's folktale "The Emperor's New Clothes," scientists are naive enough (sometimes maybe even courageous enough) to risk ridicule by proclaiming, "He hasn't got anything on."

But we shouldn't be surprised when the emperor responds by walking "more proudly than ever, as his noblemen held high the train that wasn't there at all."



BY JEFF HESTER
Jeff is a keynote speaker, coach, and astrophysicist. Follow his thoughts at **jeff-hester.com**

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Sinus Iridum stirs the imagination

The Bay of Rainbows is a visual treasure trove.

LEFT: Long waves, a mermaid, and a shark tooth — all are imagined phenomenon created by light and shadow in the Moon's Sinus Iridum region.
STEPHEN JAMES O'MEARA

RIGHT: Giovanni Cassini depicted Promontorium Heraclides as the "Moon Maiden" in his 1679 Moon map. It seems that either Cassini or the map's famous engraver, Claude Mellan, included the detail, believing that this tiny part of the Moon's surface looked like a beautiful woman.
BRITISH LIBRARY, COURTESY OF AUTHOR

The Moon never fails to surprise. This chiaroscuro world of ever-shifting shadows plays with our psyche. Wherever lies the terminator — the sharp dividing line between lunar day and night — so too do dramatic differences in darkness and light, casting some features into arresting highlights, while plunging others into an abyss of dark shadows. Sinus Iridum, the Bay of Rainbows, is one region where the low solar angle at the terminator can enhance surface texture, bringing out features that fill the sails of our imagination and activate memories that we can project onto the lunar landscape.

Part of the reason for the intrigue is Sinus Iridum's complex geology and evolution. This 160-mile-wide (258 kilometers) lava plain lies on the northwest rim of Mare Imbrium (the Sea of Storms). It is the remains of a "small" impact event. Along its northwest rim, the ejecta formed the Jura Mountains, though the range we see today is undoubtedly only a portion of the original crater wall. The crater's southeast rim was likely covered by episodic floods of basaltic lava from neighboring Mare Imbrium, which filled Sinus Iridum at least four times between 3.4 billion and 1.2 billion years ago.

Enter the imagination

Iridum's seemingly soft, smooth floor and mountainous pastiche has been a playground for the imagination for centuries, inspiring observers and artists alike, including legendary American space artist Chesley Bonestell. Perhaps their early depictions of this region paved the way for my awe when I recently turned my 3-inch refractor to the Moon. The terminator shadow had just begun to lean into the Bay of Rainbows, and the smooth floor I expected to see was no more. In its place was rolling wave after rolling wave of light and shadow, rippling into the bay like a lunar tsunami.

The visual turmoil caused by this gentle interplay of bright and dark immediately transformed a cold and frozen landscape into a seemingly animated display of long waves. In ancient times, such a sight would have lent credence to beliefs that these dark regions of the Moon were vast bodies of water.

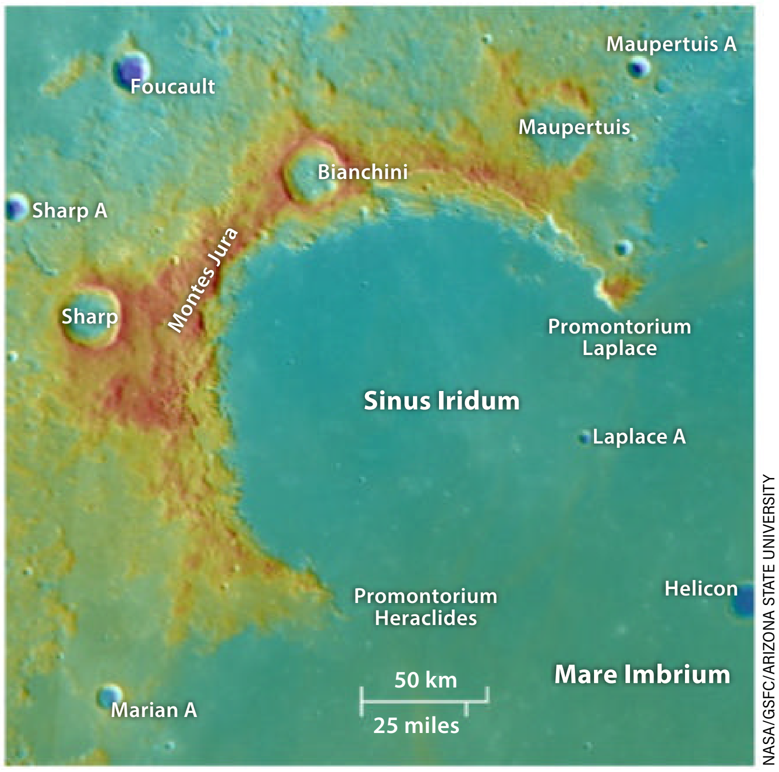
Adding to the aquatic scene was the haunting figure of a mermaid — a dramatic imagining created by the sunlit loops and shadowy folds of the Jura Mountains. This range ends in two capes: Promontorium Heraclides at the southwest tip and Promontorium Laplace at the northeast tip (which projects a slender shark-tooth shadow). Promontorium Heraclides is the mermaid's head, complete with braided hair flowing to the west. The Jura Mountain's sunlit northwest rim forms her torso, while an inverted V of jumbled terrain (near the crater Bianchini region) marks the mermaid's flipper.

Seeing Promontorium Heraclides as a woman's head is not surprising, given that it has long been known as the "Moon Maiden," a depiction that first appeared on Giovanni Cassini 1679's map of the Moon. The feature was intentionally rendered to appear like the profile of a woman's head with wind-blown hair, looking out over the Bay like a widow on watch.

That I would see a larger figure among the intense light and shadow of the Jura Mountains is also not unprecedented. In his 1953 Guide to the Moon, the late British astronomy popularizer Patrick Moore wrote, "When the terminator passes close by, the mountain peaks of the eastern border (the Juras) catch the light, and the whole bay stands out from the blackness like a handle studded with gleaming jewels." Ever since, that feature has been known as the Jeweled (or Golden) Handle Effect.

As for the waves in the Bay, these low sinuous ridges were most likely created by compressional and uplifting forces when deep, once-dormant faults reactivated. This caused surface layers to buckle along the crests of ridge-like rises — first the middle in inner bay, followed later by the outer bay. It is an example of visual artistry created by the invisible brush of global cooling on the Moon.

As always, send your observations and thoughts to sjomeara31@gmail.com.



NASA/GSFC/ARIZONA STATE UNIVERSITY

This topographic map from NASA's Lunar Reconnaissance Orbiter shows the lowest areas in blue and the highest in red.

BY STEPHEN JAMES O'MEARA
Stephen is a globe-trotting observer who is always looking for the next great celestial event.

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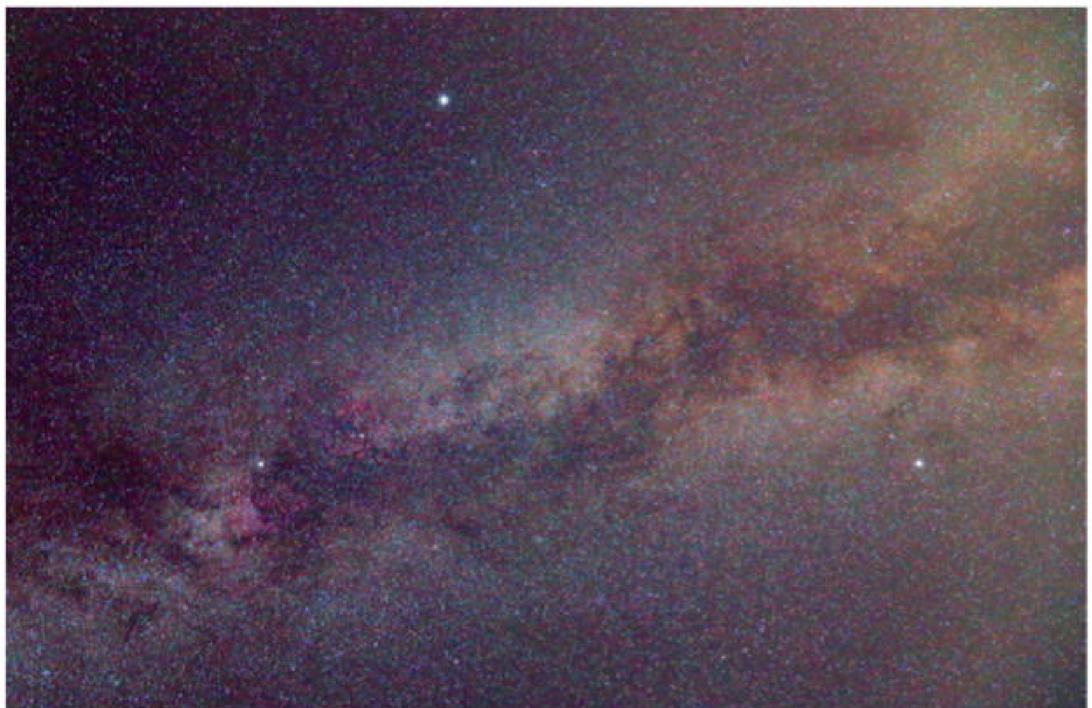
Summer jewels

Make sure to collect these treasures this July.



Vega sparkles high above the Milky Way Galaxy in this image of the Summer Triangle. JOHN CHUMACK

BY PHIL HARRINGTON
Phil is a longtime contributor to Astronomy *and the author of many books.*

Back in the January 2020 column, we toured several colorful stars in the cold winter sky. Let's head back out this month in search of summertime gems.

We begin by aiming high in the sky toward dazzling **Vega** (Alpha [α] Lyrae). The brightest member of the Summer Triangle, Vega outshines its compatriots, Deneb (Alpha Cygni) and Altair (Alpha Aquilae). Vega lies 25 light-years away and is three times larger than our Sun. The striking sapphire blue color is due to a surface temperature of around 17,000 degrees Fahrenheit (9,400 degrees Celsius), about 7,000 F hotter than our Sun. That translates to a spectral class A rating.

Our next colorful stop is too faint to see by eye, but is visible through binoculars if you know where to aim them. **T Lyrae** is one of summer's premiere carbon stars, sitting on the outskirts of the constellation Lyra. Carbon stars are categorized as spectral class C and are famous for their ruby red color. But T Lyrae is on the faint side for most binoculars — it shines around 8th magnitude, although it can vary. I can usually see it with my 10x50 binoculars from my suburban backyard but, to be successful, you need to know exactly where to look. Fortunately, it lies just 2° southwest of Vega. Aim your binoculars toward Vega and then shift the star toward the northeast side of the view. Without moving your aim, slide your eyes across the field. You'll find T Lyrae against a background of faint, white stars.

From Lyra, swing one constellation east to Cygnus. There, marking the Swan's beak, we find one of the sky's most colorful double stars: **Albireo** (Beta [β] Cygni). Albireo is made up of a 3rd-magnitude spectral class K yellow star paired with a 5th-magnitude class B blue companion. They appear separated by 35", which is tight at 10x and lower power. To split them, brace your binoculars either by mounting them on a tripod or by leaning against a fence, a parked car, or another stable surface. Higher magnification will cleave the pair apart more readily, but even at 10x, the color contrast is apparent.

Incidentally, I referred to Albireo as a double star, not a binary star. There is a difference. Binary stars are gravitationally linked to each other, while double stars are just chance line-of-sight alignments of widely separate stars. The jury is still out on whether Albireo is a true binary or an optical double. If the former, their orbital period probably exceeds 75,000 years.

As you star-surf through Cygnus with your binoculars, you will encounter many more colorful gems. One pair that always attracts my attention at this time of year is the team of 4th-magnitude **Omicron^1** (o^1) and 5th-magnitude **30 Cygni**. You'll find them 5° — about a binocular field — northwest of Deneb. They appear separated by 5.6' and may be resolvable by eye alone under very dark skies. But it will take binoculars to show their true colors. Omicron^1, a spectral class K star, has a light topaz tint, while 30, a spectral class A star, appears pearly white. Adding to this is a third star, **HD 192579**, 1.8' south of Omicron^1. This class B star appears distinctly blue, creating a very colorful triple treat.

Expanding the view, golden **Omicron^2** (o^2) **Cygni** is in the same field, 1° north-northeast of Omicron^1. Omicron^2 is the doppelganger of Omicron^1, save for the former shining about 0.3 magnitude fainter.

Let's head back out this month in search of summertime gems.

Finally, ¾° east-northeast of Omicron^2 is another carbon star, the long-period variable **U Cygni**. When near maximum brightness, U Cygni's cherry red glow reaches 6th magnitude, while at minimum, it bottoms out at magnitude 12. Its last maximum occurred in May 2020, which means it is currently gaining brightness, with an expected peak sometime in August. Keep an eye out for it this summer. When visible, U Cygni forms an attractive double star with an 8th-magnitude costar 2' southeast.

This short list of summertime gems is just the tip of the iceberg. We will return to find more next summer. If you have a favorite colorful star, no matter the season, tell me about it. Contact me through my website, philharrington.net.

Until next month, remember that two eyes are better than one.

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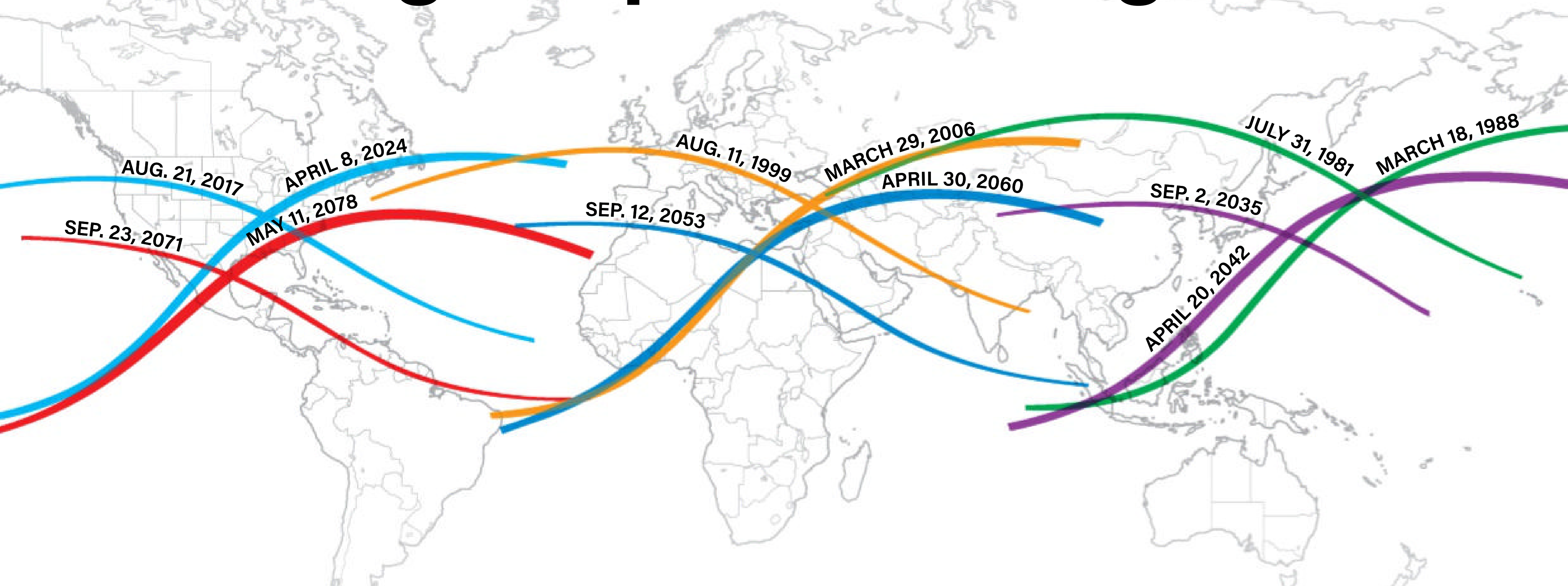
Chasing eclipse crossings



Every 18 years and 11 days or so, the geometry of an eclipse path repeats. The August 2017 and the upcoming April 2024 events are just the latest in a series of intersecting eclipses. *ASTRONOMY:* ROEN KELLY

Q THE NEXT U.S. TOTAL SOLAR ECLIPSE, WHICH IS IN 2024, INTERSECTS THE PATH OF THE 2017 ECLIPSE AND THE DURATION OF TOTALITY WILL ALSO BE CLOSE TO 2017'S. IS IT A COMMON OCCURRENCE TO HAVE TWO ECLIPSES BISECT WITH SIMILAR MAXIMUM TOTALITY DURATIONS?

Launie Wellman
Festus, Missouri

A As it turns out, the Moon, Earth, and Sun return to approximately the same geometry about every 18 years 11 days or so, depending on the number of leap years during such eclipse cycles. This period of time is known as the saros. And yes, it is common for intersecting eclipses to more or less duplicate after that period of time.

So, the 2017 and 2024 eclipses, which cross because they travel across the U.S. in different directions, are only the latest in a long line of such crossings.

The 2017 eclipse is part of saros series 145 and the 2024 eclipse is part of series 139. You can calculate the next pair of intersecting eclipses in these series by adding another eclipse cycle — again, that's 18 years 11 days — to each. Where these eclipse crossings will land follows their own pattern, crossing in the same general vicinity every three saroses.

The totalities of each saros series are also similar, with saros 145 eclipses lasting between 2¾ and 3¼ minutes, while saros 139 eclipses last between about 4½ and 5½ minutes.

As to why these mirroring eclipses occur, it boils down to cosmic coincidence. A lunar month — the time it takes for the Moon to complete one phase cycle, in this case New Moon to New Moon — lasts about 29 days 12 hours 44 minutes 3 seconds. A draconic month — so named after the belief that eclipses were caused by a dragon eating the Sun — is the time it takes for the Moon to orbit the Earth and recross the ecliptic, the path of the Sun in our sky. This occurs about every 27 days 5 hours 5 minutes 36 seconds. After a saros, the two periods are only off by about 52 minutes, making for similar eclipse paths. So if the eclipse paths of two different saros series happen to cross, they will do so in each successive cycle.

SAROS SERIES 145	SAROS SERIES 139	CROSSING LOCATION
July 31, 1981	March 18, 1988	Pacific Ocean
Aug. 11, 1999	March 29, 2006	Turkey
Aug. 21, 2017	April 8, 2024	United States
Sept. 2, 2035	April 20, 2042	Pacific Ocean
Sept. 12, 2053	April 30, 2060	Northern Libya
Sept. 23, 2071	May 11, 2078	Northern Mexico

The length of totality depends on the size of the Moon's shadow on Earth, which in turn hinges on how far away from Earth the Moon happens to be. The elliptical period is about 27 days 13 hours 18 minutes 33 seconds. After one saros, it too happens to be very closely aligned with the lunar and draconic months, off by only a few hours. The minor differences do eventually build up, however. A saros series typically only lasts somewhere between 1,226 and 1,550 years.

I have posted links to dual-path maps on my website for the International Astronomical Union's Working Group on Eclipses at http://eclipses.info as well as on my own Williams College eclipse website at http://totalsolareclipse.org.

Jay Pasachoff
Field Memorial Professor of Astronomy, Williams College, Williamstown, Massachusetts

Q | WHAT IS THE DIFFERENCE BETWEEN THE OBSERVABLE UNIVERSE AND THE WHOLE UNIVERSE?

Vitthal Nath
Jharkhand, India

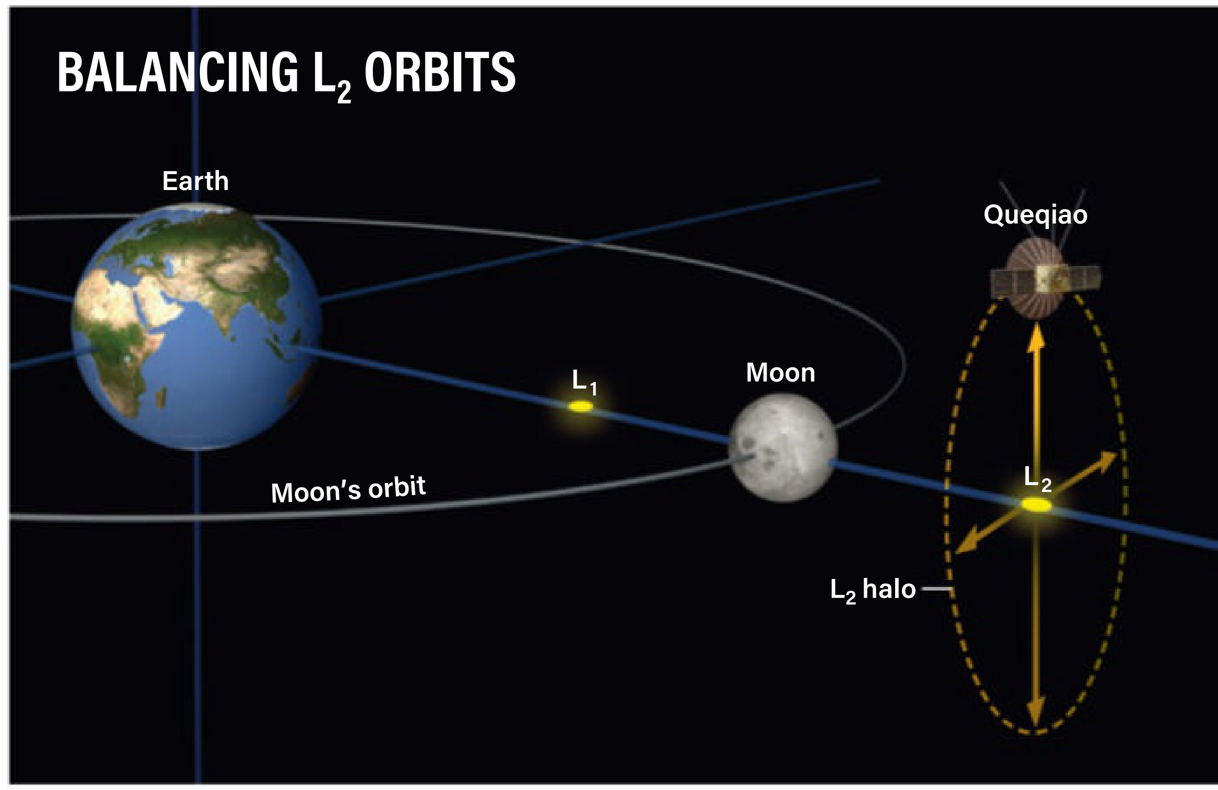
A | About 13.8 billion years ago, the Big Bang kicked off the universe, filling it with matter, dark matter, and dark energy. Since then, the universe has expanded into what we see (and don't see) today.

Light, the fastest thing in the universe, has a speed limit of about 186,000 miles per second (about 300,000 km/s). This means that, from our viewpoint, we can only see as far as the light from the farthest objects has been able to travel in the time since the Big Bang. You can essentially think of the observable universe as a sphere surrounding any point in the cosmos — in our case, Earth. The radius of that sphere is 46 billion light-years.

It may seem counterintuitive to think of the cosmos as existing beyond the observable universe, especially if even light has a finite speed. But the universe's expansion rate isn't limited by the speed of light. So, while we're limited to just the observable universe, space is constantly growing. The exact size of the whole universe is unknown, but estimates put it at around 23 trillion light-years in diameter. Other cosmologists say that the whole universe may simply be infinite.

Caitlyn Buongiorno
Associate Editor

NASA's Ultraviolet Coverage of the Hubble Deep Field survey captures much of the observable universe in this image. NASA/ESA



The illustration above shows Queqiao's halo orbit around the Earth-Moon L_2 point, which is maintained via small thruster corrections. *ASTRONOMY*: ROEN KELLY

Q | THE QUEQIAO SATELLITE ORBITS AROUND THE L_2 LAGRANGE POINT LOCATED BEHIND EARTH AND THE MOON TO RELAY COMMUNICATIONS FROM CHINA'S LUNAR LANDERS BACK TO EARTH. HOW IS IT ABLE TO ORBIT THAT POINT IF THE GRAVITATIONAL FORCES THERE ARE BALANCED?

Michael G. Blazeski
Dillonvale, Ohio

A | Lagrange points are locations around a two-body system where the gravitational forces of the two objects, in this case Earth and the Moon, are equal to the centrifugal force. This allows for a satellite to stay in place with relatively little motion at one of the five Lagrange locations. However, the gravitational forces for L_1, L_2, and L_3 are only balanced well in one radial direction, meaning these points are unstable.

You can think of it like keeping a ball on your head. Your head will prevent the ball from falling straight to the ground, but it will quickly roll off to one side unless you balance it by moving around a little bit.

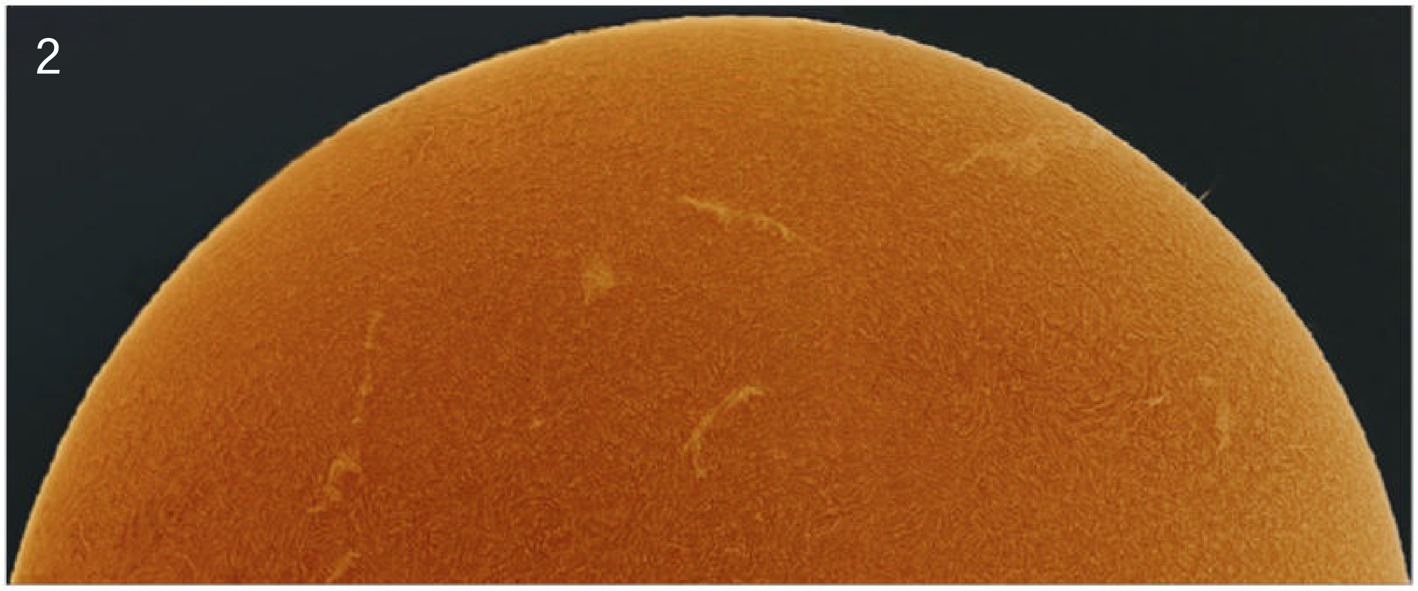
Similarly, in order for Queqiao to stay put at L_2, it would need to have exactly the right velocity and location. However, it can easily drift away in a plane perpendicular to the imaginary line connecting Earth and the Moon. If the satellite gets slightly ahead of the Earth-Moon line, the Moon's gravity pulls it back and slows it down. Conversely, when Queqiao starts to fall behind, the Moon will pull it forward and accelerate it again. This gravitational dance only requires slight adjustments from the craft's thrusters to keep it roughly in orbit around L_2.

Heino Falcke
Professor of Astroparticle Physics and Radio Astronomy, Radboud University, Nijmegen, Netherlands

SEND US YOUR QUESTIONS

Send your astronomy questions via email to askastro@astronomy.com, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

Cosmic portraits

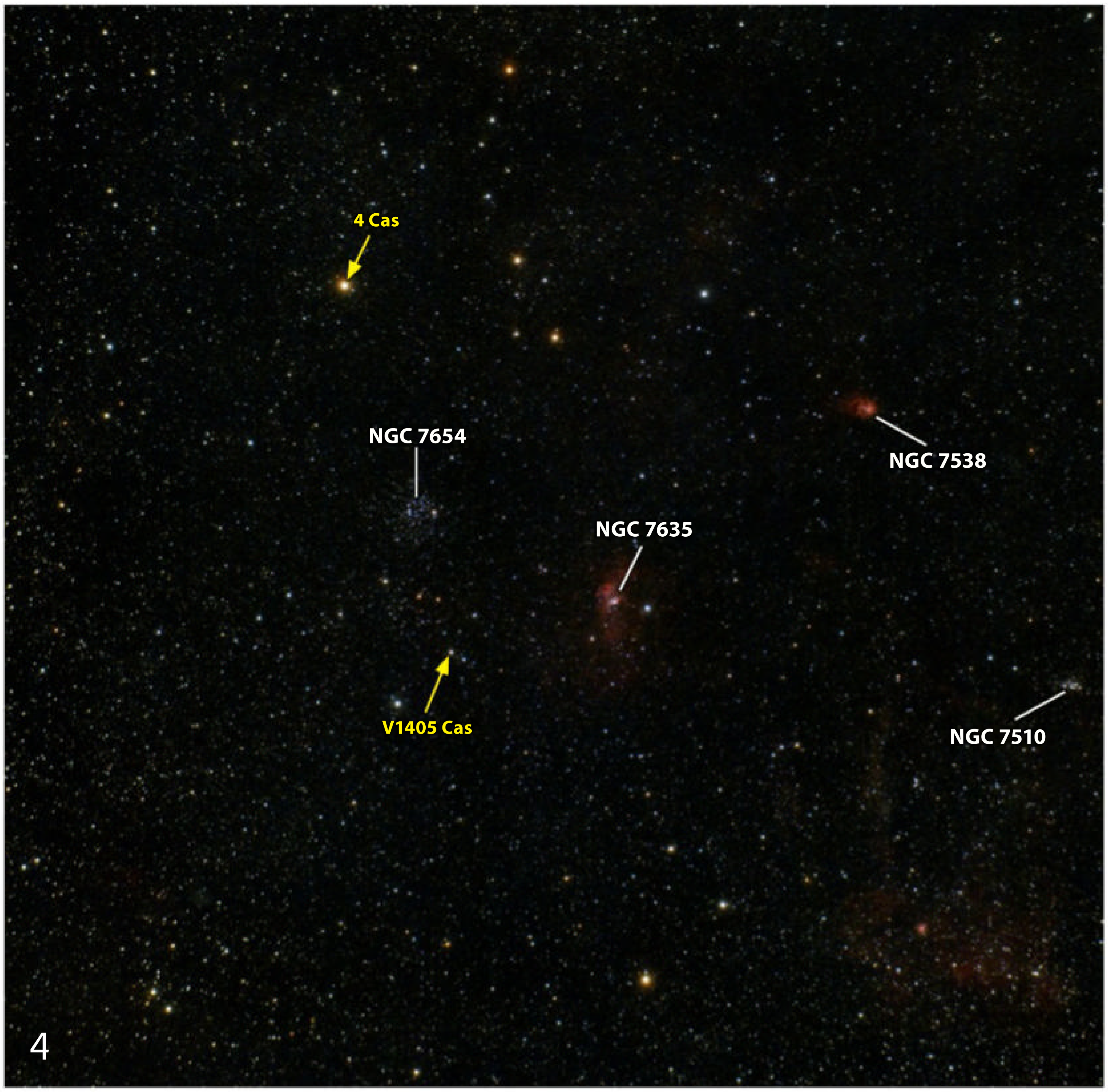


2. INCANDESCENT FILAMENTS
In this Hα image, the Sun is laced with numerous filaments — structures of plasma that arc above the star's surface. When imaged through a solar filter, they appear as dark lines because they are cooler than the Sun's surface below; in this inverted and colorized image, they appear as bright tendrils. (When these plasma structures appear on the limb of the Sun, they are called prominences.) The image is a mosaic of two exposures, each consisting of 300 stacked video camera frames. **• *Michael P. Caligiuri***

1. TALE OF TWO GALAXIES
This spectacular pair of Milky Way mosaics is made of 270 images and a total exposure of 2,500 hours over nine years. The photographer used three different focal lengths: 14mm for the wide sky background, 85mm for the bulk of the Milky Way band, and 530mm to capture fine nebula detail. Two different filter combinations are shown: The top image is narrowband Hα/OIII/SII and the bottom strip is taken in HαRGB. **• *Alistair Symon***

3. RED SKIES AT NIGHT
The photographer calls this "the most intense airglow activity [I've seen] during my 10-year career." The image was taken in Iran's salt desert, Dasht-e Kavir, Jan. 15, 2021. The exposure was 45 seconds at f/4 and ISO 6400. **▪ *Amirreza Kamkar***

4. CAUGHT IN ITS PRIME
The nova V1405 in Cassiopeia was discovered March 18, 2021, by amateur Yuji Nakamura in Japan. It was shining at magnitude 9.6 and still brightening, peaking two days later just below naked-eye visibility at around magnitude 7.6. This image was captured before dawn March 21 using a 2.8-inch refractor and a Canon Ra at ISO 800 and 14 frames of 120-second exposures. **▪ *Tara Mostofi/Alexandru Barbovschi***



SEND YOUR IMAGES TO:
Astronomy Reader Gallery, P.O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to **readergallery@astronomy.com.**

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A SPIRAL WITH A TWIST

Galaxies come in many shapes and sizes, but few deliver the visual delights of M106 in Canes Venatici. Glittering star clusters, glowing gas clouds, and dense dust lanes delineate the galaxy's magnificent spiral arms. Look closely, however, and you'll see a flood of reddish gas streaming from M106's active core. A supermassive black hole weighing 40 million Suns not only energizes this jet, but also warps the galaxy's inner disk. M106 spans some 130,000 light-years and lies 23 million light-years from Earth. It is the dominant member of a group that includes irregular galaxy NGC 4248 (lower right) and dwarf galaxy UGC 7356 (left). Astronomers captured this portrait with the 4-meter Mayall Telescope atop Kitt Peak in Arizona. KPNO/NOIRLAB/NSF/AURA


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September 2021
Evenings of unbridled delights

The evening sky teems with bright planets. Of the four solar system worlds on display this month, **Venus** stands out. The brilliant planet dominates the western sky from shortly after sundown until it sets around 9:30 P.M. local time. Venus begins September in Virgo, passing 1.7° north of that constellation's brightest star, 1st-magnitude Spica, on the 5th. At magnitude –4.1, the planet appears 100 times brighter than the star. Venus continues to press eastward as the month progresses, crossing into Libra shortly after midmonth.

If you haven't been following Venus' appearance through a telescope, now is the time to start. This month sees the planet's disk swell and its gibbous phase wane. In early September, Venus spans 15" and appears 73 percent lit; by month's end, it measures 19" across and the Sun lights up 63 percent of its Earth-facing hemisphere.

Mercury also graces the western evening sky. The innermost planet reaches greatest elongation September 14, when it lies 27° east of the Sun and stands 13° high an hour after sunset. This marks the peak of its best evening show of 2021. Mercury glows at magnitude 0.2 at greatest elongation and dims slightly as September winds down. It makes a fine companion to Spica — hovering within 2° of the star — during the month's final 10 days.

A telescope reveals dramatic changes on Mercury during September. On the 1st, the planet appears 6" in diameter and 74 percent lit. By the time the month ends, Mercury shows a 9"-diameter disk and a 20-percent-lit crescent phase.

While Venus and Mercury rule the western sky after sunset, Jupiter and Saturn reign in the east. The two giant planets reside at opposite ends of Capricornus, adding stunning focal points to this otherwise dim constellation. Both planets reached opposition in August, so they are superbly placed high in the early evening sky.

You won't mistake **Jupiter** for any other celestial body. Gleaming at magnitude –2.8, it appears significantly brighter than any other starlike object except Venus. The giant world spends all month within 2° of Capricornus' brightest star, magnitude 2.8 Delta (δ) Capricorni.

Be sure to spend some time viewing Jupiter through a telescope. With an equatorial diameter of 48", the giant world presents a large disk full of detail. Even the smallest scope reveals two dark cloud belts, one on either side of a brighter zone that coincides with the planet's equator.

Saturn stands out in western Capricornus. Although the magnitude 0.3 planet pales in comparison to Jupiter, it is still one of the sky's brightest objects. And the ringed world's telescopic appearance is at least the equal of its brighter neighbor. Saturn's disk measures 18" across in mid-September while the gorgeous ring system spans 41" and tilts 19° to our line of sight. During moments of good seeing, you should be able to pick out the inky-black Cassini Division that separates the outer A ring from the brighter B ring.

Alas, the fifth naked-eye planet remains out of sight. **Mars** will pass behind the Sun in early October and won't return to view until December.

The starry sky

The constellation Pavo the Peacock rides high in the southern sky on September evenings. It is one of the four constellations collectively referred to as the "southern birds" — the others being Phoenix the Phoenix, Grus the Crane, and Tucana the Toucan.

On some star charts, you'll find the word "Peacock" within the constellation along with "Pavo." Because a constellation's English and Latin names rarely appear together on charts, you might think this is an error. But Peacock is actually the proper name of the star Alpha (α) Pavonis, which lies in far northern Pavo near that constellation's border with Indus and Telescopium.

The story behind Peacock's name is intriguing. Until the 1930s, Alpha Pav had no proper name. Although the magnitude 1.9 star is fairly prominent, astronomers simply referred to it by its Greek letter designation.

As World War II neared, however, the ability to navigate while flying at night was becoming increasingly important — and bright stars played a vital role in that endeavor. But two of the so-called air-navigation stars did not have proper names and were known only by their Greek letters: Alpha Pav and the similarly bright Epsilon (ε) Carinae.

As Donald H. Sadler wrote in *A Personal History of H.M. Nautical Almanac Office*, the Royal Air Force insisted that the stars used in its manual must have names. Sadler and W.A. Scott together came up with an answer: Because Alpha Pav was Pavo's brightest star, they decided to call it "Peacock." Epsilon Car also needed a name, and they decided to call it "Avior." Although the latter's origin is less clear, there seems to be an obvious connection to aviation.

Sadler mentions that the Director of the Royal Geographical Society, A.R. Hinks, strongly objected to using the invented star names. But the International Astronomical Union ultimately disagreed and added Peacock and Avior to its list of approved star names in July 2016.

Peacock is a spectroscopic binary — a star whose duplicity shows up only through analysis of its spectrum. In 1907, American astronomer Heber Curtis observed spectral lines of hydrogen, helium, carbon, and magnesium to determine that the two stars orbit each other once every 11.8 days.

STAR DOME

HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

10 P.M. September 1
9 P.M. September 15
8 P.M. September 30

Planets are shown at midmonth

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

STAR MAGNITUDES

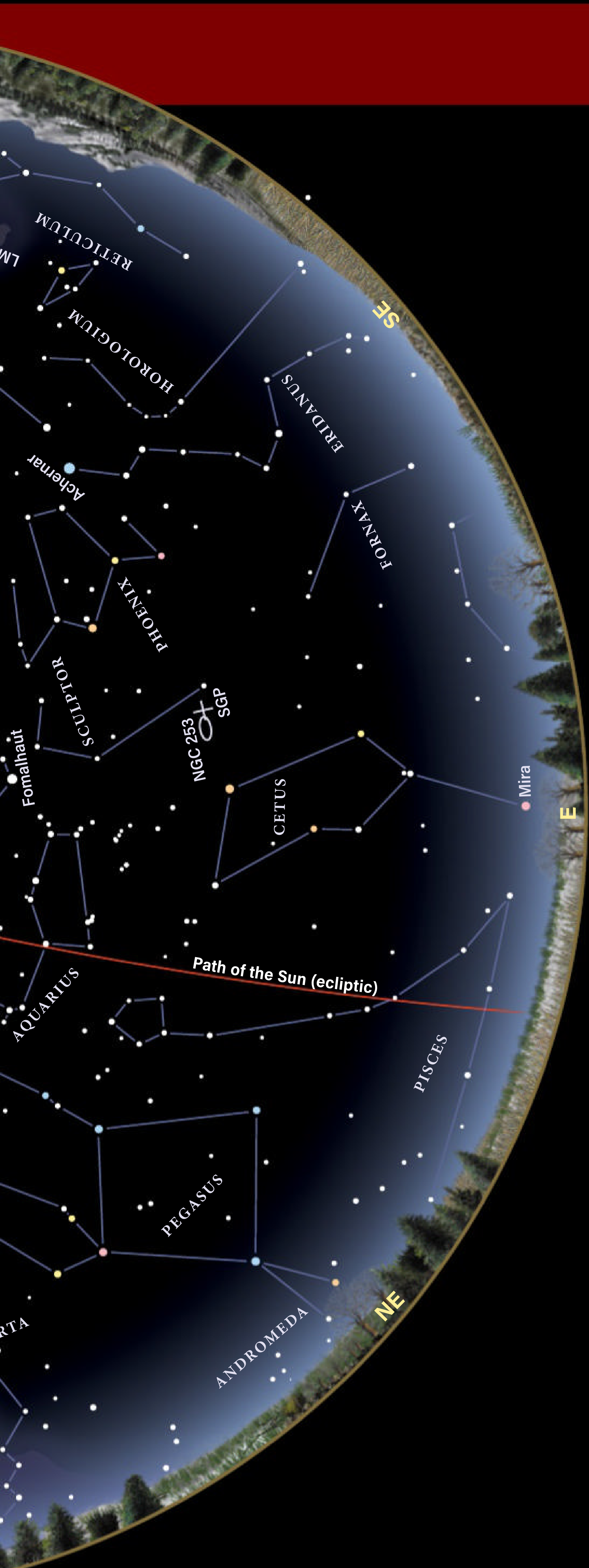
- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**



SEPTEMBER 2021

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
			1	2	3	4
5	6	7	8	9	10	11
12	13	14	15	16	17	18
19	20	21	22	23	24	25
26	27	28	29	30		

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

5 Venus passes 1.7° north of Spica, 6h UT

7 New Moon occurs at 0h52m UT

8 The Moon passes 7° north of Mercury, 20h UT

10 The Moon passes 4° north of Venus, 2h UT

11 Asteroid Pallas is at opposition, 2h UT

The Moon is at perigee (368,461 kilometers from Earth), 10h03m UT

13 First Quarter Moon occurs at 20h39m UT

14 Mercury is at greatest eastern elongation (27°), 4h UT

Neptune is at opposition, 9h UT

17 The Moon passes 4° south of Saturn, 3h UT

18 The Moon passes 4° south of Jupiter, 7h UT

20 The Moon passes 4° south of Neptune, 9h UT

Full Moon occurs at 23h55m UT

22 September equinox occurs at 19h21m UT

23 Mercury passes 1.7° south of Spica, 12h UT

24 The Moon passes 1.3° south of Uranus, 16h UT

26 The Moon is at apogee (404,640 kilometers from Earth), 21h44m UT

27 Mercury is stationary, 4h UT

29 Last Quarter Moon occurs at 1h57m UT

30 Mercury passes 1.7° south of Spica, 15h UT